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TURBOCHARGING OF SMALL INTERNAL COMBUSTION ENGINE AS A MEANS OF--ETC(U)

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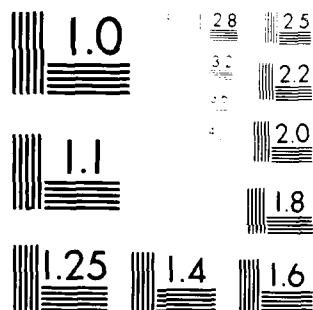
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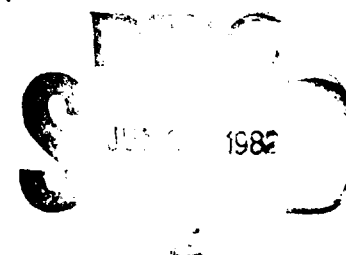
FINAL REPORT

CONTRACT NO. DAAK70-80-C-0146

TURBOCHARGING OF SMALL INTERNAL
COMBUSTION ENGINE AS A MEANS
OF IMPROVING ENGINE / APPLICATION
SYSTEM FUEL ECONOMY -
FURTHER TURBOCHARGER IMPROVEMENTS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Improvements to a small diesel engine turbocharger were made based on data gathered during a previous Army contract. The improved turbocharger was fabricated and tested on a small, four cylinder, 239 CID diesel engine. Engine dynamometer test data revealed a 2 to 9 percent reduction in fuel consumption at all points over the operating envelope. A turbocharger was operated for 1011 hours at speeds between 70000 and 78000 rpm without incident. The ball bearings were in excellent condition at the		

20.

end of the test.

A math model of the engine and turbocharger was generated. The model was used to estimate "13 Mode Federal Diesel Emissions Cycle", the "LA4" driving cycle and the application of the VATN turbocharger to a diesel engine driven generator set. A recommendation was made to build a gen set demo unit. A fuel savings of 8 to 10 percent was estimated for a 30KW DED generator set.

Summary

Under a previous contract (DAAK70-78-C-0031) a small turbocharger was fabricated and tested on a four cylinder diesel engine. This turbocharger features variable area turbine nozzles, a ball bearing supported rotor and a self-contained lubrication system. Using results from this previous effort, the current contract (DAAK70-80-C-0146) addressed turbocharger improvements, engine testing of the improved turbocharger, bench testing to learn more about the ball bearings and limited bearing durability demonstration, and development of a math model to predict turbocharger and engine operating condition and engine performance.

Turbocharger modification included new compressor and turbine trims which better matched the engine flow requirements. The VATN system was redesigned to give a broader range of turbine flow capacity variation. Additional mods were considered to reduce the heat transfer from turbine to compressor.

The improved turbocharger was instrumented and installed on a diesel engine. Engine dynamometer test data shows a 2 to 9 percent improvement at every operating condition from 40 to 100 percent speed and 25 to 100 percent load at each speed.

Bench testing to define the optimum set of bearing parameters was not completed. A turbocharger was operated 1011 hours at speeds between 70000 and 78000 rpm without incident; this exceeded the contract goal by 300 hours.

A computer math model was created. The model was used to determine improved match between the turbocharger and engine. The model was also used to estimate emissions and BSFC for the "13 Mode Federal Emission Diesel Cycle". Fuel consumption for three diesel engines operating in a VW Rabbit automobile over the LA4 driving cycle was calculated. Fuel consumption improvements of 50 to 64 percent were estimated. A simple VATN control strategy was assessed. Application of the VATN turbocharger to a DED generator set was analyzed. The VATN eliminates turbocharger lag thereby allowing the engine to meet military gen set response requirements. A recommendation was made to replace a six cylinder, N/A diesel with a four cylinder diesel employing a VATN turbocharger. Fuel savings of 8 to 10% were estimated.



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PREFACE

This report was prepared by Aerodyne Dallas under U.S. Army Contract DAAK70-80-C-0146, issued by the Electro-Mechanical Division of the U.S. Army Mobility Equipment Research and Development Command, Fort Belvoir, and was under the technical direction of Mr. John R. Arvin.

This report covers the results of the work performed from October 1980 to February 1982, at which time the program was completed.

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I. INTRODUCTION

Rising fuel costs have put a premium on improving engine fuel efficiency. Turbocharging of internal combustion engines can be used to effect an improvement in fuel economy. This is accomplished largely by down-sizing and/or reducing the rotational speed and turbocharging back to the original, normally aspirated, engine power level. For diesel engines, additional benefits may be realized due to improvements in engine air fuel ratio. As engine size is reduced, turbocharging becomes increasingly difficult. The adverse effects of bearing losses and reduced component efficiencies are magnified in the smaller turbocharger.

Under a previous Army contract, DAAK70-78-C-0031, a turbocharger with several advanced features was built and successfully tested on a John Deere 4239T diesel engine. Engine fuel consumption and emissions were improved over a majority of the operating speed and load range. Even though the previous program was a success, several areas of improvement and further investigation were identified.

These areas included:

- Improved matching of compressor and turbine to engine
- Reduced heat transfer from turbine to compressor
- Improvement to VATN system including airfoil shapes
- Further information about optimum bearing operational parameters
- Substantial extension of engine-turbocharger mathematical model
- Application of mathematical model to estimate 13 mode federal diesel engine cycle, the LA4 cycle, and turbocharger control strategy

The work presented in this final report has been directed toward the above items.

II. DESIGN MODIFICATIONS AND REMATCHING

Results of previous work had identified several areas where the turbocharger could be improved. A cross section and associated nomenclature are shown in figure 1.

COMPRESSOR

Design Modification

An analysis of the previous test data showed that the compressor was operating at 60% efficiency at rated load and speed and at a pressure ratio of 2.0. Therefore, it was decided to increase the compressor flow size 16% and make a vaneless diffuser. A vaneless diffuser will reflect a reduction in peak efficiency but give a broader operating range. There was ample room to provide a vaneless diffuser by machining the vanes from the compressor backwall casting. The diffuser is formed by a converging section followed by a parallel wall section, (see figure 2). The converging section has a radius ratio of 1.432 which provides for substantial reduction in the tangential component of velocity leaving the rotor wheel. The parallel wall portion then diffuses through an area ratio of 1.320. The constant velocity scroll used to collect the flow from the diffuser discharge is unchanged from the original design.

The compressor wheel and diffuser design modifications were made in conjunction with one another. The compressor wheel tip shroud profile was altered to (1) increase the flow capacity 16% above the original design value and (2) reduce the diffusion in the rotor wheel. Also, these changes had to be geometrically consistent with the diffuser inlet. The iterative design process resulted in the aforementioned vaneless diffuser and a new wheel tip shroud contour. The tip shroud profile is 8.6° from normal at the rotor exit - diffuser inlet. The rotor area ratio was reduced from 1.56 to 1.11.

Compressor Rig Test

The compressor was tested on the Aerodyne turbocharger test rig. The test equipment is the same as that reported in detail for the previous contract. Basically, The turbine is driven by exhaust gases from a diesel engine which have passed through a settling tank. Diesel engine air flow is measured along with four turbine inlet temperatures, nine turbine exit temperatures, two turbine inlet stagnation pressures (static pressure in settling tank), and three exit static pressures. Compressor measurements include four inlet temperatures, nine exit temperatures, four inlet stagnation pressures, and eight exit stagnation pressures. This data along with turbocharger rotational speed allow detailed component performance to be determined. The compressor operating point is set by adjusting a compressor discharge throttle valve and turbine vane position or diesel engine speed (mass flow to turbine).

FIGURE 1- AERODYNE TURBOCHARGER CROSSECTION

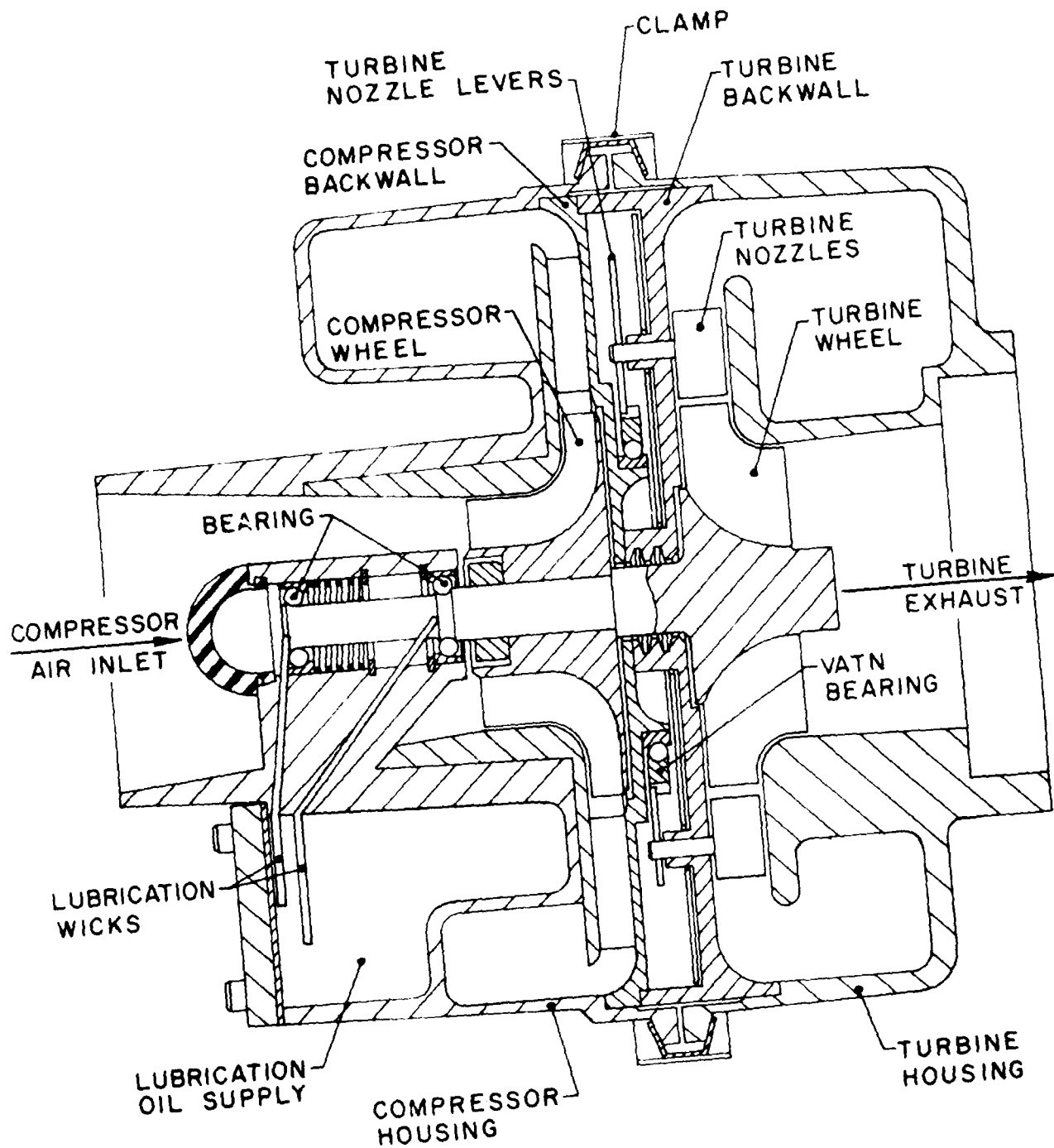


FIGURE 2-COMPRESSOR GEOMETRY MODIFICATIONS

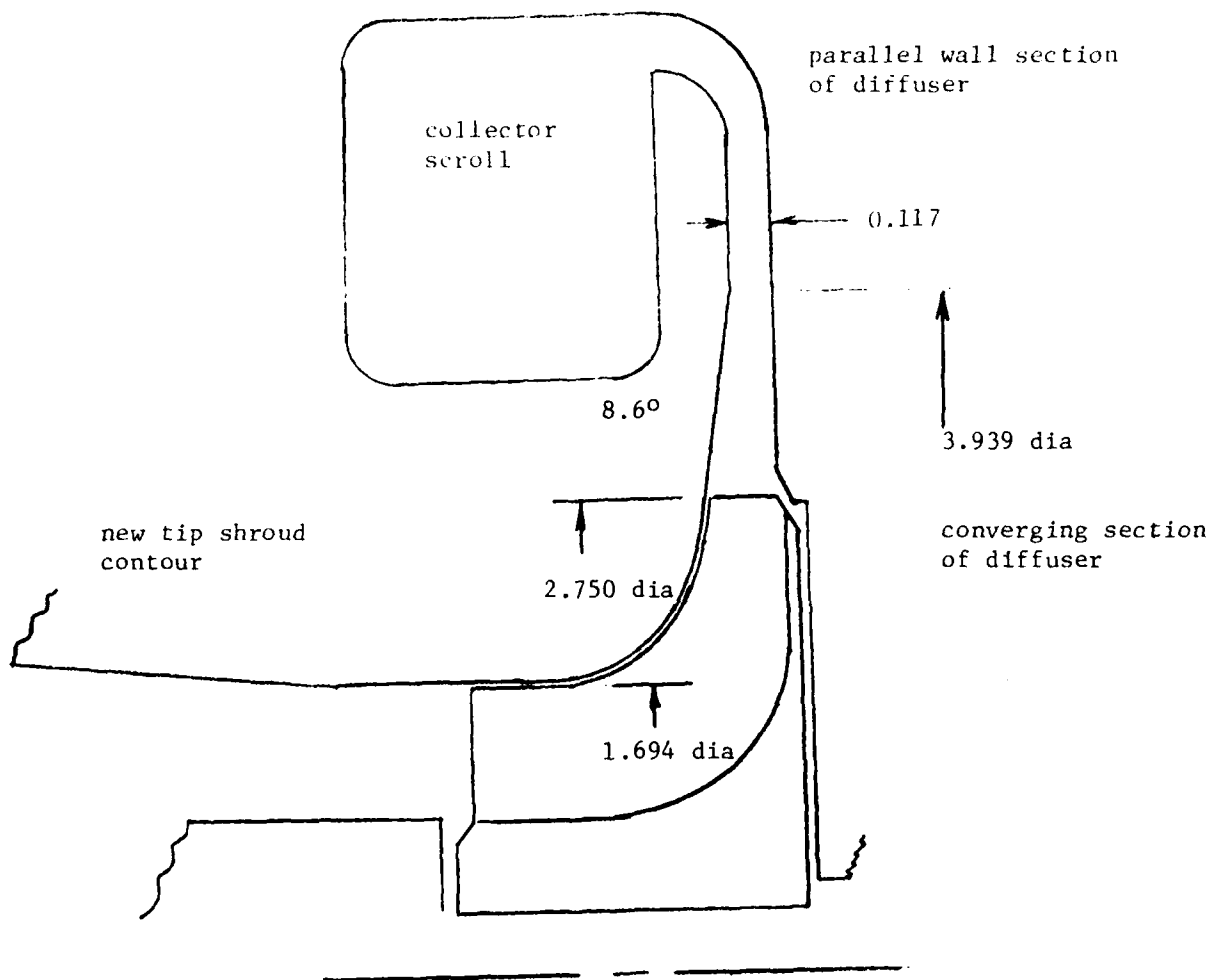
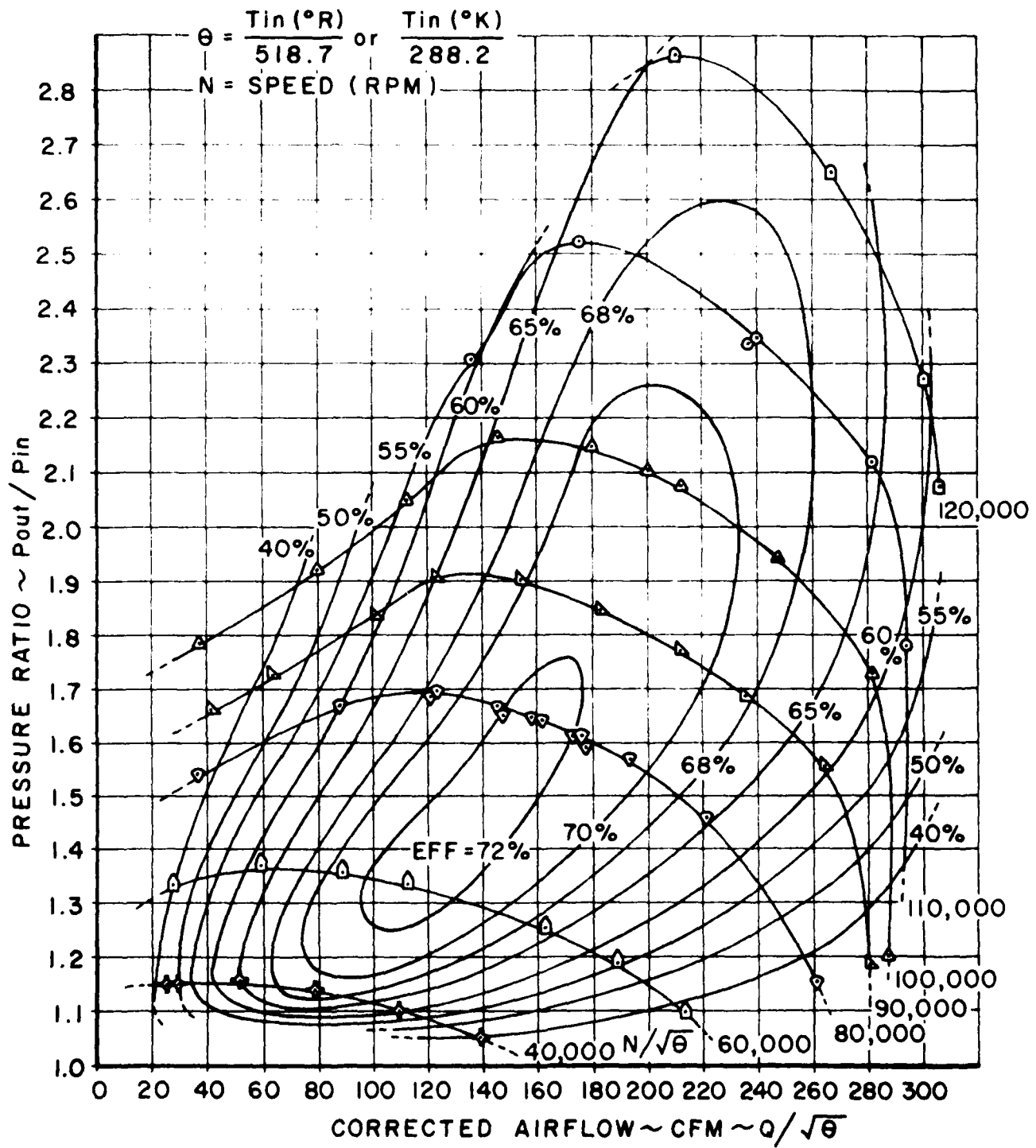


FIGURE 3-
COMPRESSOR MAP



A compressor map was generated from the rig test data which shows compressor efficiency as a function of corrected volumetric flow rate, pressure ratio, and corrected speed, (see figure 3). A peak efficiency of slightly over 72% was measured which is 3 points lower than the original vaned diffuser design. Stable compressor operation was observed even at very low flow rates. At 100000 rpm the lowest corrected flow rate tested was 37 cfm at 1.78 pressure ratio. At the same speed and pressure ratio, the maximum flow was 275 cfm. At flow rates between 37 and 130 cfm, at 100000 rpm, the compressor is in a "soft surge"; but can operate at these conditions indefinitely without damage. Also, the resulting pressurized air is stable.

Heat Transfer

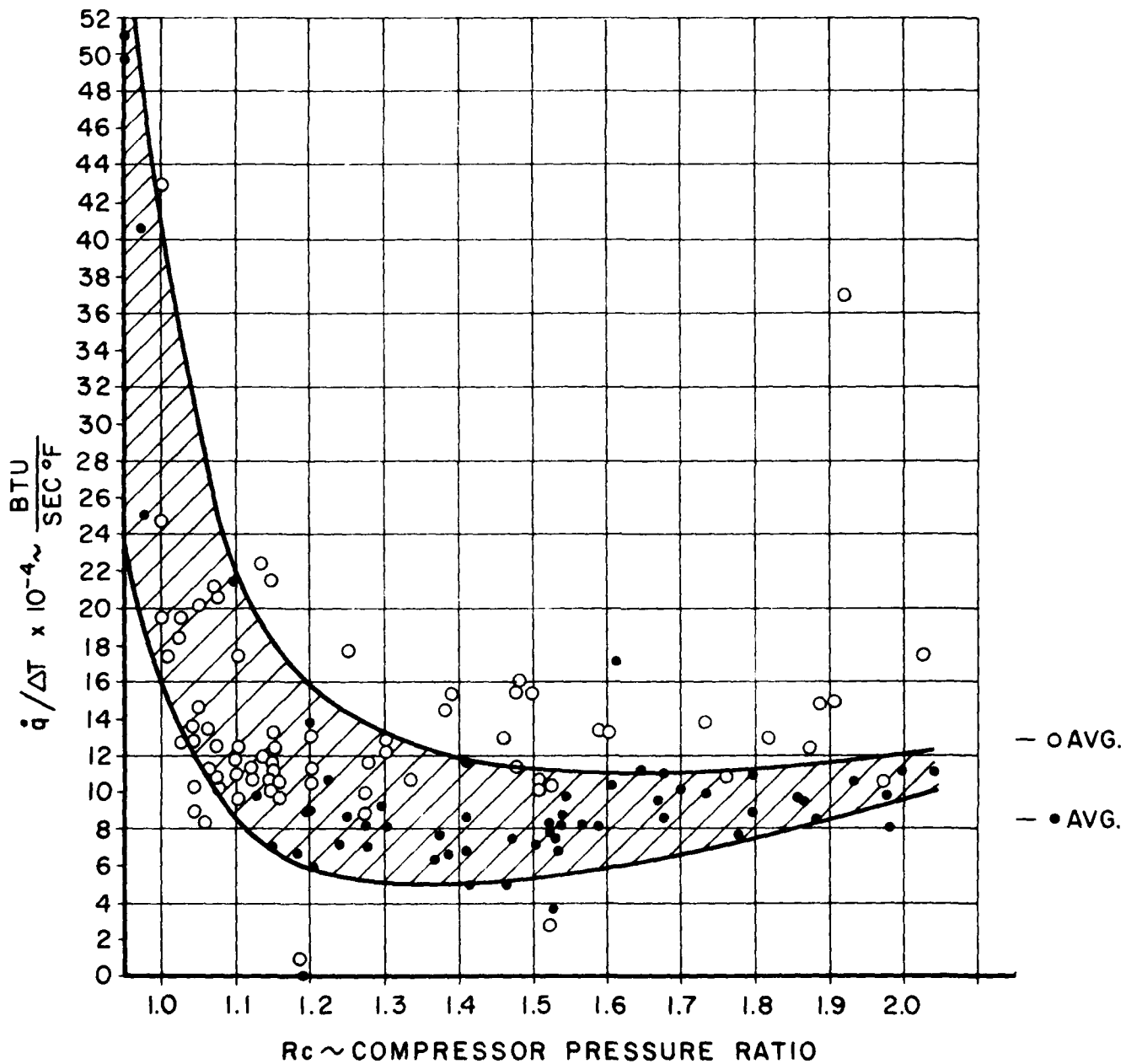
From figure 1 it can be seen that the general arrangement of the turbocharger places the turbine close to the compressor. This leads to heat transfer from the turbine to the compressor. In order to quantify the amount of heat transfer, the process was assumed to be characterized by an "overall heat transfer coefficient" (OAHT) which was defined as the amount of heat transfer (energy per unit time) divided by the difference in temperature between turbine inlet and compressor discharge. To deduce this coefficient, compressor test rig data and turbocharger data from the engine test performed during the previous contract were used. A value for OAHT was determined which resulted in the compressor efficiency calculated from engine data equal to the component test rig value i.e. the compressor map. The compressor rig data was generated with a low turbine inlet temperature, 250°F to 350°F; therefore, the overall heat transfer is minimal. Steps were taken to reduce the heat transfer even before the beginning of the current contract. These mainly included minimizing the area normal to the flow of heat across the outer diameter of the turbine backwall. Figure 4 presents the OAHT as a function of compressor pressure ratio for the original turbocharger test in the previous contract and for the turbocharger as modified since that point in time. The engine tests were conducted at Southwest Research Institute, San Antonio, for the previous contract. The OAHT was reduced from .0013 Btu/sec°F. Wall temperature measurements were made at various locations on the turbine and compressor housings. This data along with material conductivities, and estimated heat transfer coefficient were used to calculate the heat flow through several paths via a heat balance.

Four paths were identified as follows:

- path 1 - From turbine housing to compressor housing through "V" clamp
- path 2 - From turbine backwall at outer diameter to compressor backwall
- path 3 - Across the air gap between backwalls
- path 4 - Along shaft from turbine wheel to compressor

FIGURE 4-
DEDUCED OVERALL HEAT TRANSFER COEFFICIENT

○ SOUTHWEST RESEARCH INST. TESTING (PREVIOUS CONTRACT)
• AERODYNE TESTING



The contribution of each of these four paths was estimated to be in the following proportion after the initial heat transfer mods were made.

path 1 - 27% of total

path 2 - 49% of total

path 3 - 16% of total

path 4 - 8 % of total

Further modifications were considered. These included:

- a - Adding another insulator next to the compressor backwall between the VATN bearing and the outer diameter of the compressor backwall.
- b - Make a ceramic turbine backwall with the ceramic material properties biased toward low thermal conductivity.
- c - Thermal barrier coating the turbine backwall
- d - Insulate "V" clamp from housings
- e - Additional reductions in area normal to heat flow path 2.

The cost and lead-time for item b were not within the constraints of the current program. Item c was discontinued because of the risk of the thermal barrier coming loose from the backwall. Item d was tried; but the insulating material would not allow the "V" clamp to remain tight thereby allowing leakage.

Items a and e were employed. Item e took on the form of a heat dam (groove) which was machined in the outer ring of the turbine backwall.

TURBINE

VATN Design Modification

The original design allowed for the turbine vanes to be moved ± 10 degrees from a nominal position. The VATN bearing, which serves as a unison ring, was modified in order that the turbine nozzle vanes could be moved ± 14 degrees from nominal. The vane air foil shape was redefined. The airfoil chord was reduced from 0.94 to 0.84 inches, (see figure 5). The new airfoil shape not only provides additional clearance between the vane trailing edge and the rotor blade leading edges (at full open vane position); but, also the vane channel convergence was improved. It is aerodynamically desirable to have the channel formed by two adjacent vanes to converge as the gas passes from the inlet to the throat. Figure 6 presents the channel width as a function of distance along the channel for the original vane shape in both the full open and closed positions.

Three new shapes were considered. Figure 7 shows the new vane shape selected. Figure 8 presents the channel convergence of the new design which is much improved as compared to that shown in figure 6 for the original design.

FIGURE 5-
ORIGINAL DESIGN TURBINE VANE IN CLOSED POSITION

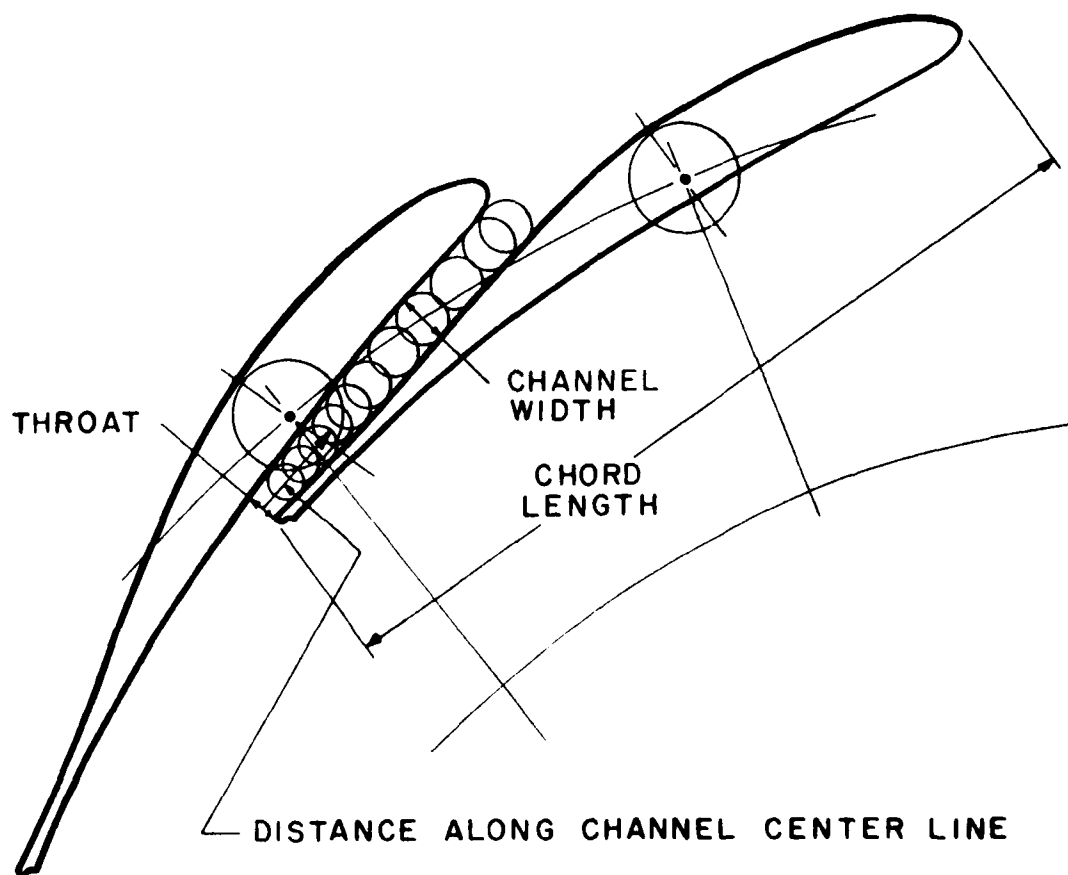


FIGURE 6 -
ORIGINAL DESIGN
TURBINE VANE CHANNEL CONVERGENCE

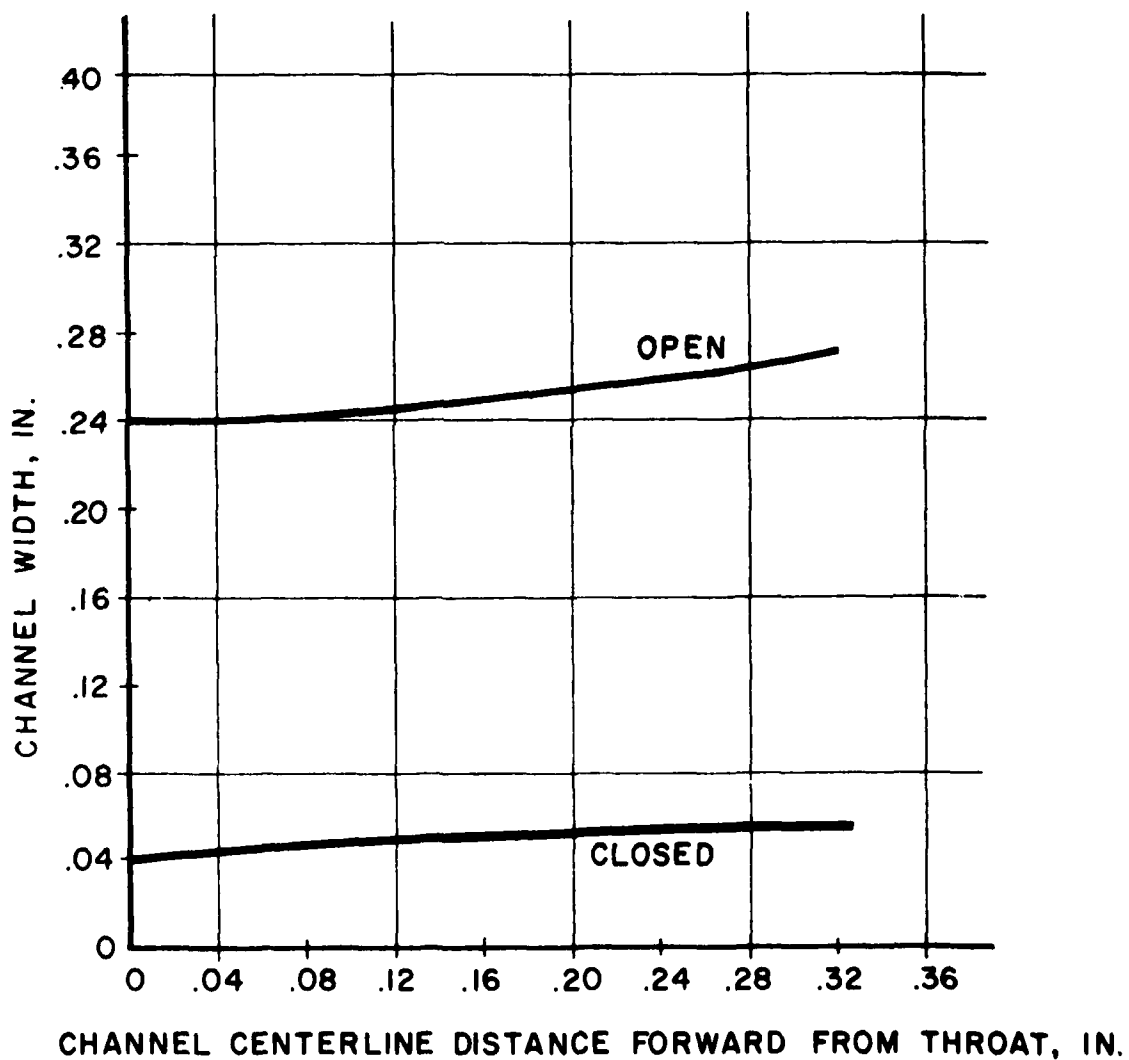


FIGURE 7-

NEW TURBINE VANE SHAPE IN CLOSED POSITION

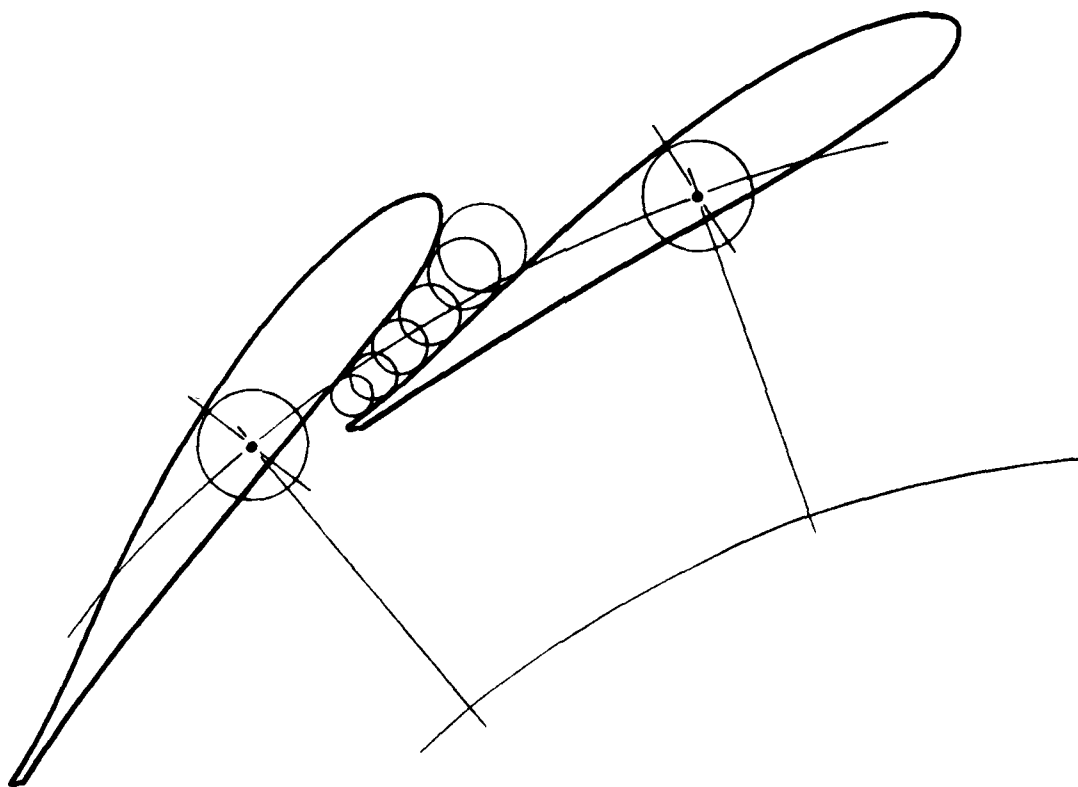
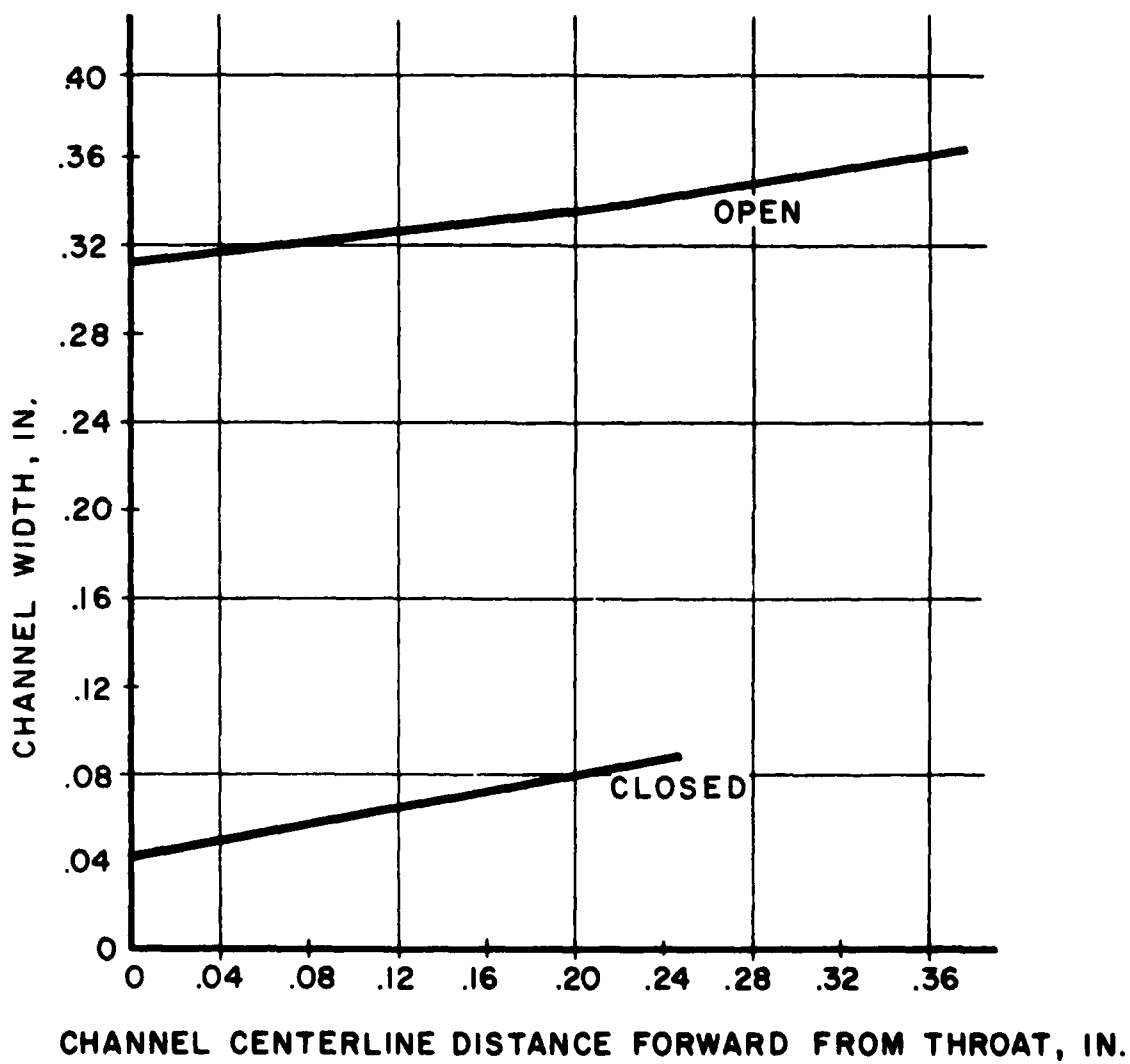


FIGURE 8-
NEW TURBINE VANE CHANNEL CONVERGENCE



Turbine Size Reduction

The engine to turbocharger matching was assessed via a computerized mathematical model of the turbocharger and engine system. This model was used to determine the change in turbine and compressor trim (flow size) to better match the engine requirements. The new compressor trim was reported in a previous section of this report. The new turbine trim was estimated to be 0.250 rather than 0.370. These numbers are the vane height (and rotor blade inlet height) in inches. Consideration was given to 0.200 turbine but rig tests showed that an efficiency loss of 3 to 13 percent may offset the reduced size benefits. Therefore, the 0.250 turbine was selected.

III. ENGINE TESTING

The new design changes were incorporated and two model 2.661/D turbochargers were built for testing on the John Deere 4239T diesel engine. One turbocharger was used for bench testing the other for the engine tests.

The purpose of the engine testing was to demonstrate the improved engine fuel consumption with the VATN turbocharger as compared to the original, bill of materials turbocharger, an Airesearch T04.

TEST FACILITY AND INSTRUMENTATION

All testing was conducted at Aerodyne Dallas, Dallas, Texas. The engine tests were performed on a Midwest type MW1014A eddy current, engine dynamometer. The dynamometer is controlled with a Digalog electronic controller. The Hewlett Packard 3052A Automatic Data Acquisition System, which services the turbocharger test rig and was described in the DAAK70-78-C-0031 final report, is also used to record and analyze data from the engine dynamometer test facility. Up to 48 pressures can be measured via a Multiple Scanivalve System which sends transducer signals to the data acquisition system. Engine torque and speed signals are taken directly from the dynamometer controller into the Hewlett Packard 3052A. A Hewlett Packard 5300B counter sends turbocharger rotational speed directly to the 3052A data acquisition system.

Engine instrumentation included four compressor inlet and four compressor exit temperatures and static pressures. The turbine also had four temperatures and static pressures at the inlet and exit. Iron constantine thermocouples were used at all locations. Compressor inlet and turbine inlet stagnation pressures were calculated from measured static pressure, temperature, mass flow, and the known area. Engine air flow is measured using a Meriam model 50MC2-4F Laminar Flow Element placed some 35 feet upstream of the compressor inlet. This 35 foot length also contains a 55 gallon drum used to dampen the pulses emitted from the engine. Fuel flow was measured using a balance and weights. The time required to consume a known mass of fuel was measured thereby giving fuel mass flow rate. The relative humidity, fuel weight, and time are entered into the data acquisition computer manually. Fuel temperature (entering the fuel pump) and crankcase oil temperature were measured for documentation purposes.

TEST PROCEDURE

The John Deere 4239T diesel engine with the Aerodyne Dallas VATN turbocharger was mounted on the engine dynamometer and instrumented. The data acquisition and analysis computer program which was previously generated was used for this test. This program was used to acquire and analyze engine dynamometer data taken for the same engine operating with the bill of materials turbocharger, an Airesearch T04. This baseline test was run previous to the current contract and will be compared to the VATN turbocharger results in the next report section.

The test was conducted by operating the engine at speeds of 1000, 1500, 2000, and 2500 rpm, and loads of 0, 25, 50, 75, and 100% at each speed. At each point in this matrix two or three data points were taken at different turbine vane throat dimensions. At 1000, 1500, 2000, and 2500 rpm, 100% torque values were 197.5, 216.5, 209.0, and 194.3 ft-lb respectively. In addition, data was also taken at the maximum fueling which the fuel pump would deliver at 1000, 1500, 2000, and 2500 rpm. An attempt was made to take data at idle speed and various loads but engine over heating was experienced and this portion of the test plan was deleted. One data point was taken at 747 rpm and 178 ft-lb (100% load).

TEST RESULTS

Copies of the computer output sheets are shown in the Appendix. Reading numbers (Kdg #) 1, 2, 3, 19, and 46 were for checkout purposes; fuel consumption measurements were not taken at these points. Therefore, of the 67 readings taken, 63 are valid fuel consumption points. The BSFC (brake specific fuel consumption) results are shown in figures 9, 10, 11, and 12 for 1000, 1500, 2000, and 2500 rpm respectively. Also shown in these figures are the BSFC values for the bill of materials, fixed area, turbocharger (T04) at the same operating conditions. This data was taken on the same engine, same dynamometer, and using the same measurement techniques and data analysis program. The effect of the VATN turbocharger, as compared to the fixed area turbocharger, on engine fuel consumption can be stated succinctly as follows. At every point in the speed/load operating envelope of the engine there is a VATN turbocharger vane position at which the engine fuel consumption is improved as compared to that with the fixed area turbocharger. The improvement was 2 to 9% for all data points except one which was 31%.

The data shown in the Appendix includes two compressor efficiency values. The first value is calculated based on measured compressor pressure ratio, inlet temperature and exit temperature. The second efficiency corrected the compressor exit temperature by the 0.0008 Btu/°F/sec constant discussed earlier. Recall that this constant approximately accounts for heat transfer between turbine and compressor. This data was plotted as a function of compressor pressure ratio for each of the four engine speeds. Also included in these figures, 13 through 16, is the compressor efficiency from the compressor map. It can be seen from figures 13 through 16 that the 0.0008 overall heat transfer constant corrects the compressor efficiencies measured on the engine back to the compressor map values. The data at 1000 rpm, figure 13, shows the most divergence between corrected and map efficiencies. This is most likely due to the effect of low Reynolds numbers at low flow rates.

FIGURE 9-
SPECIFIC FUEL CONSUMPTION
AS A FUNCTION OF VANE THROAT POSITION
AT 1000 RPM FOR A JOHN DEERE
3.9 LITER , D.I. DIESEL

		BMEP	
	LOAD	PSI	BAR
○	25 %	31.2	2.15
□	50 %	62.4	4.30
◇	75 %	93.5	6.44
△	100 %	124.6	8.60

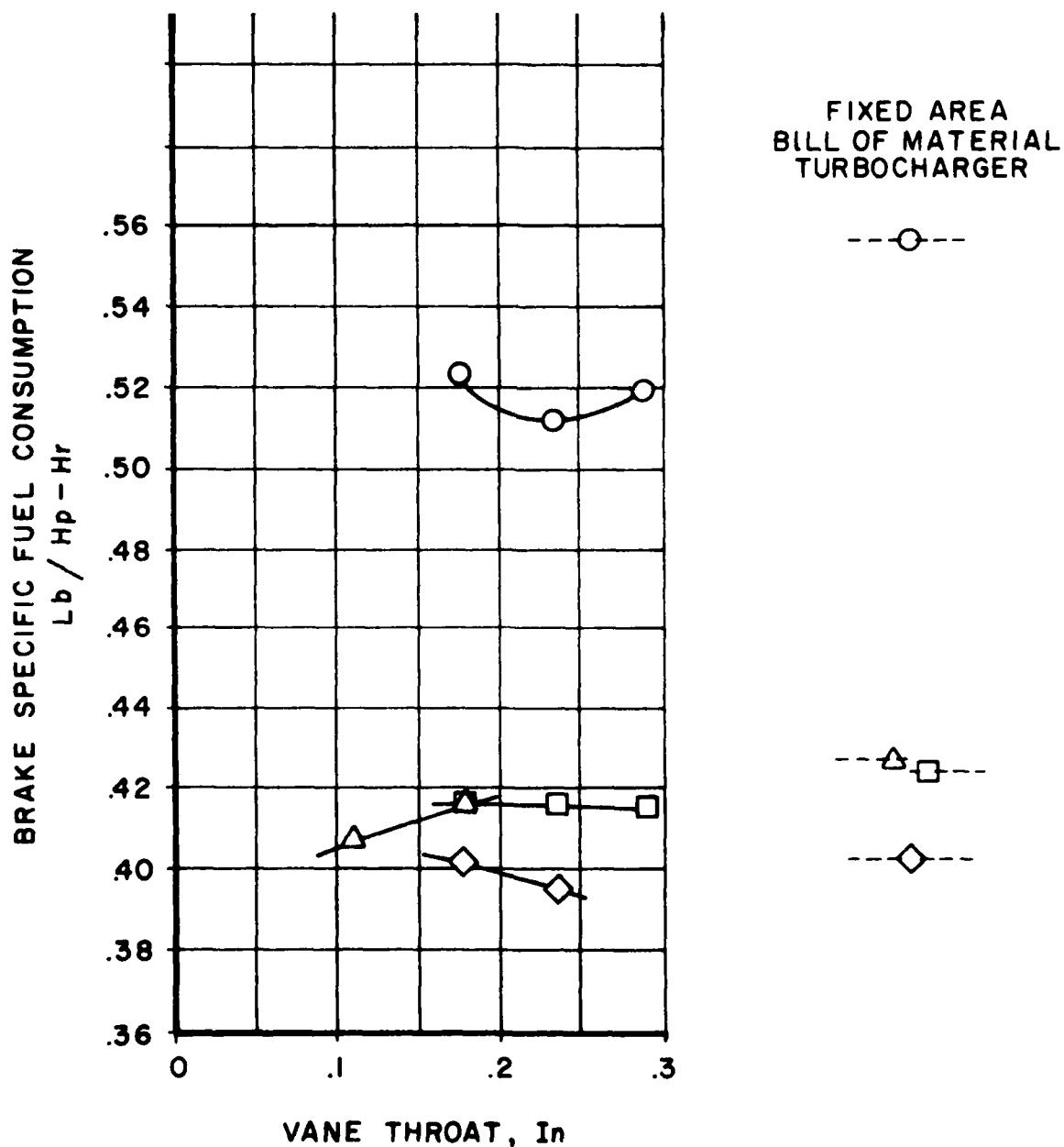


FIGURE 10-
SPECIFIC FUEL CONSUMPTION
AS A FUNCTION OF VANE THROAT POSITION
AT 1500 RPM FOR A JOHN DEERE
3.9 LITER, D.I. DIESEL

- 25 % (BMEP= 34.1 , 2.35 BAR)
- 50 % (BMEP= 68.3 , 4.71 BAR)
- ◇ 75 % (BMEP= 102.5 , 7.07 BAR)
- △ 100% (BMEP= 136.6 , 9.42 BAR)

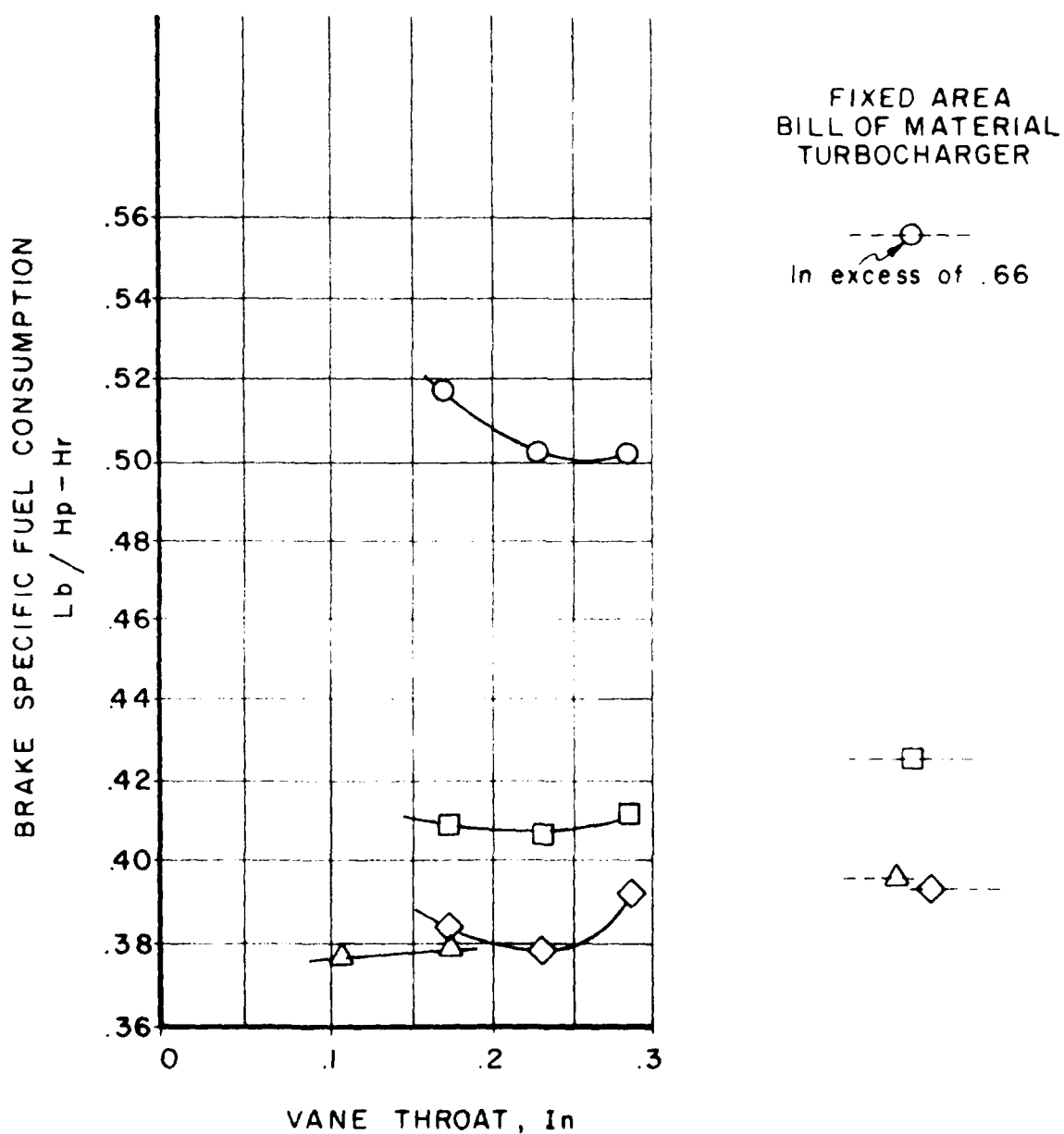


FIGURE II-
SPECIFIC FUEL CONSUMPTION
AS A FUNCTION OF VANE THROAT POSITION
AT 2000 RPM FOR A JOHN DEERE
3.9 LITER, D.I. DIESEL

	LOAD	BMEP	
		PSI	BAR
○	25%	33.0	2.27
□	50%	65.9	4.55
◇	75%	98.9	6.82
△	100%	131.9	9.09

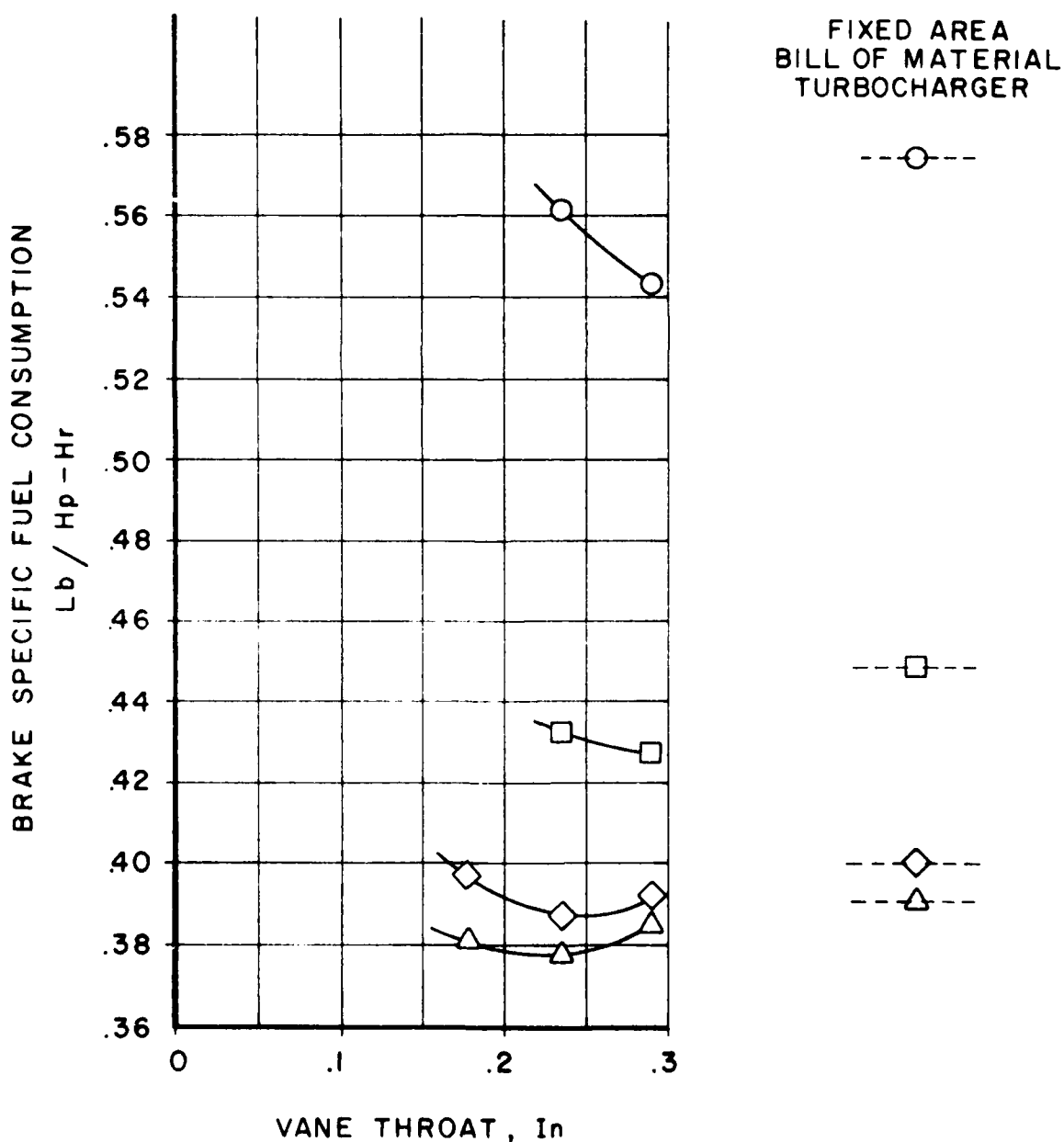


FIGURE 12-
SPECIFIC FUEL CONSUMPTION
AS A FUNCTION OF VANE THROAT POSITION
AT 2500 RPM FOR A JOHN DEERE
3.9 LITER , D.I. DIESEL

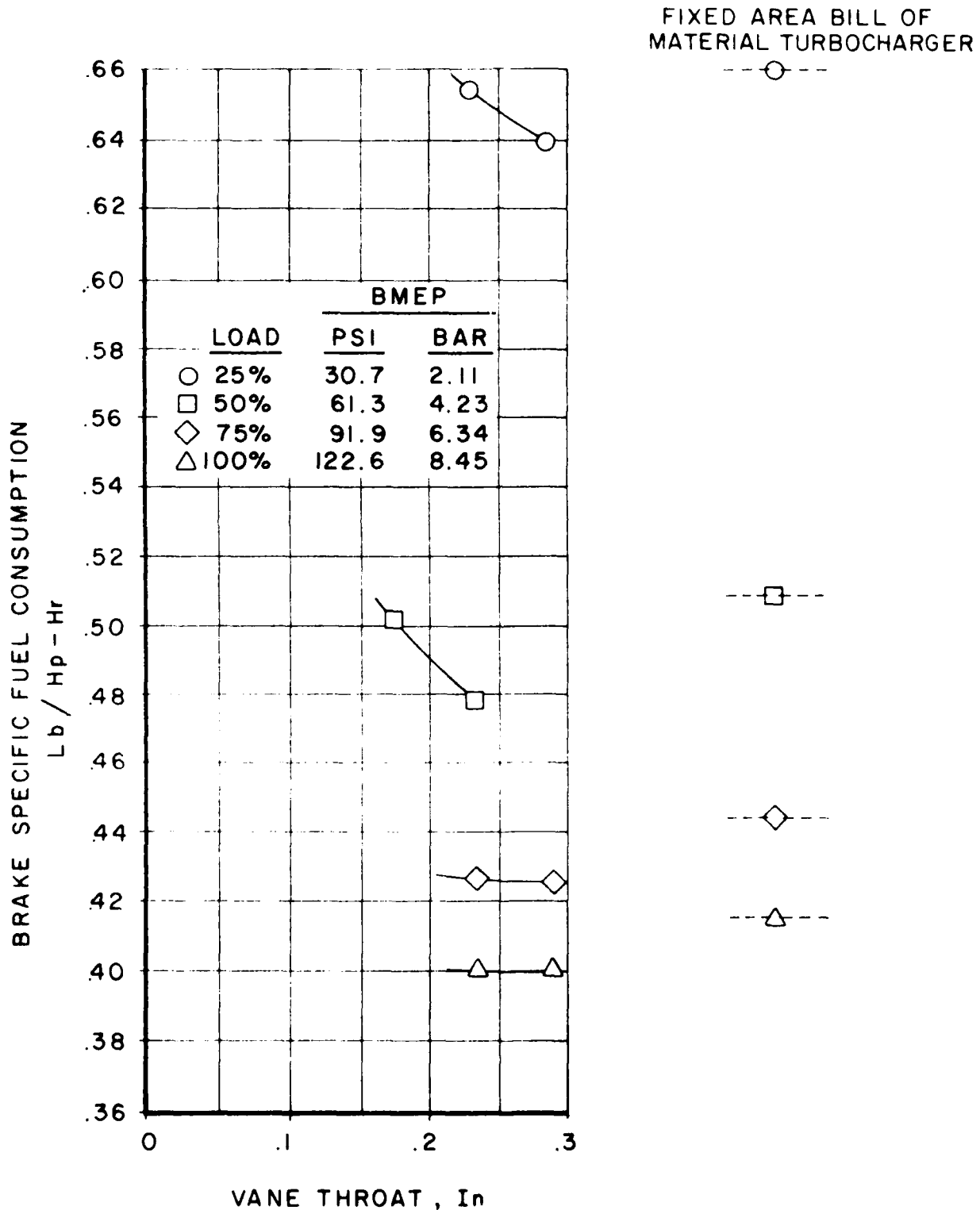


FIGURE 13-
APPARENT EFFECT OF HEAT TRANSFER
ON COMPRESSOR EFFICIENCY
DATA FROM JOHN DEERE 3.9 LITER DIESEL

1000 RPM ENGINE SPEED
 OPERATING LINE

- ◇ APPARENT EFFICIENCY
- ◇ EFFICIENCY W/O .0008 BTU/SEC/°F H.T.
- COMPRESSOR MAP

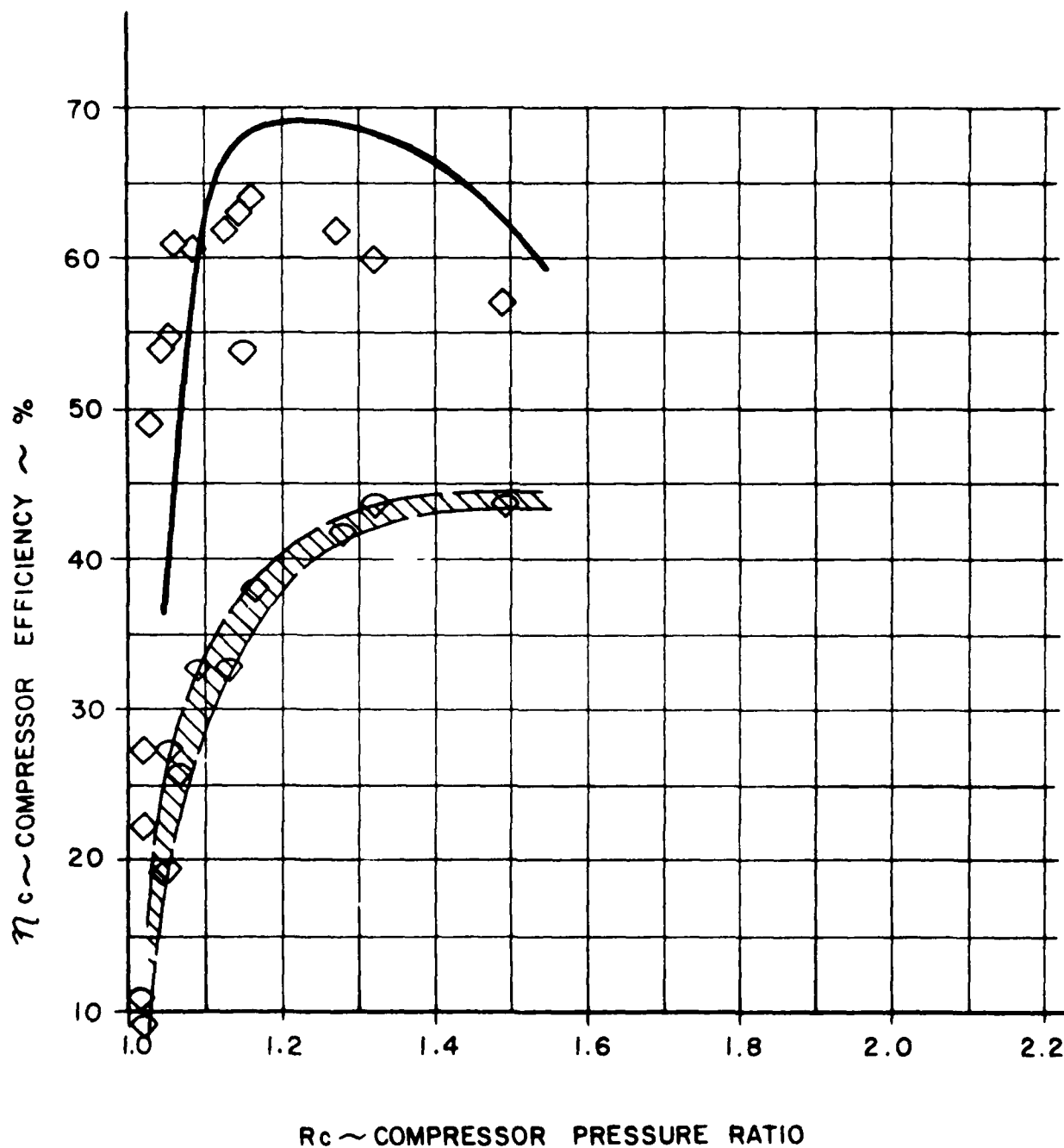


FIGURE 14-
APPARENT EFFECT OF HEAT TRANSFER
ON COMPRESSOR EFFICIENCY
DATA FROM JOHN DEERE 3.9 LITER DIESEL

1500 RPM ENGINE SPEED
 OPERATING LINE

- ◇ APPARENT EFFICIENCY
- ◇ EFFICIENCY W/O .0008 BTU/SEC/°F H.T.
- COMPRESSOR MAP

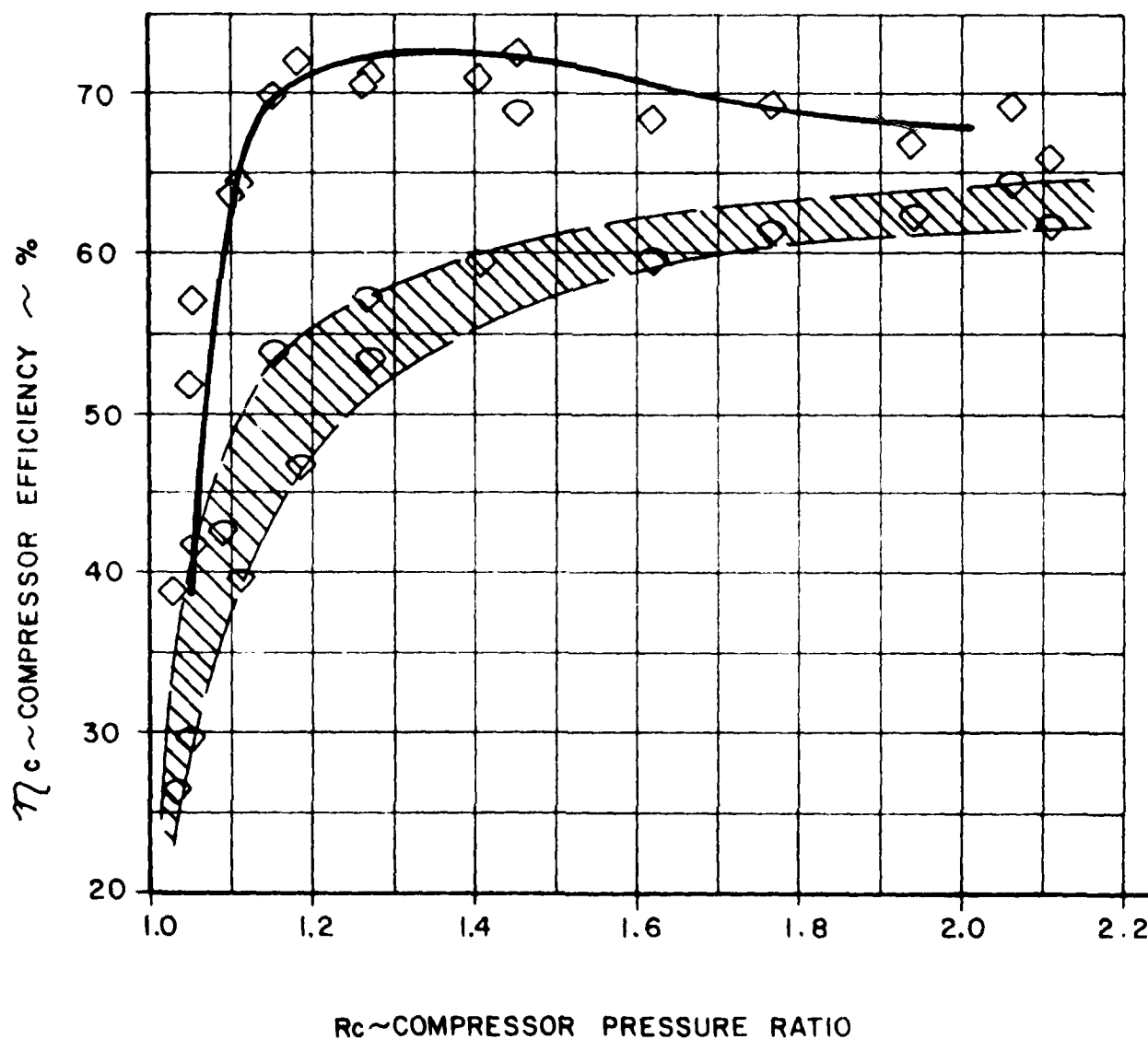


FIGURE 15 -
APPARENT EFFECT OF HEAT TRANSFER
ON COMPRESSOR EFFICIENCY
DATA FROM JOHN DEERE 3.9 LITER DIESEL

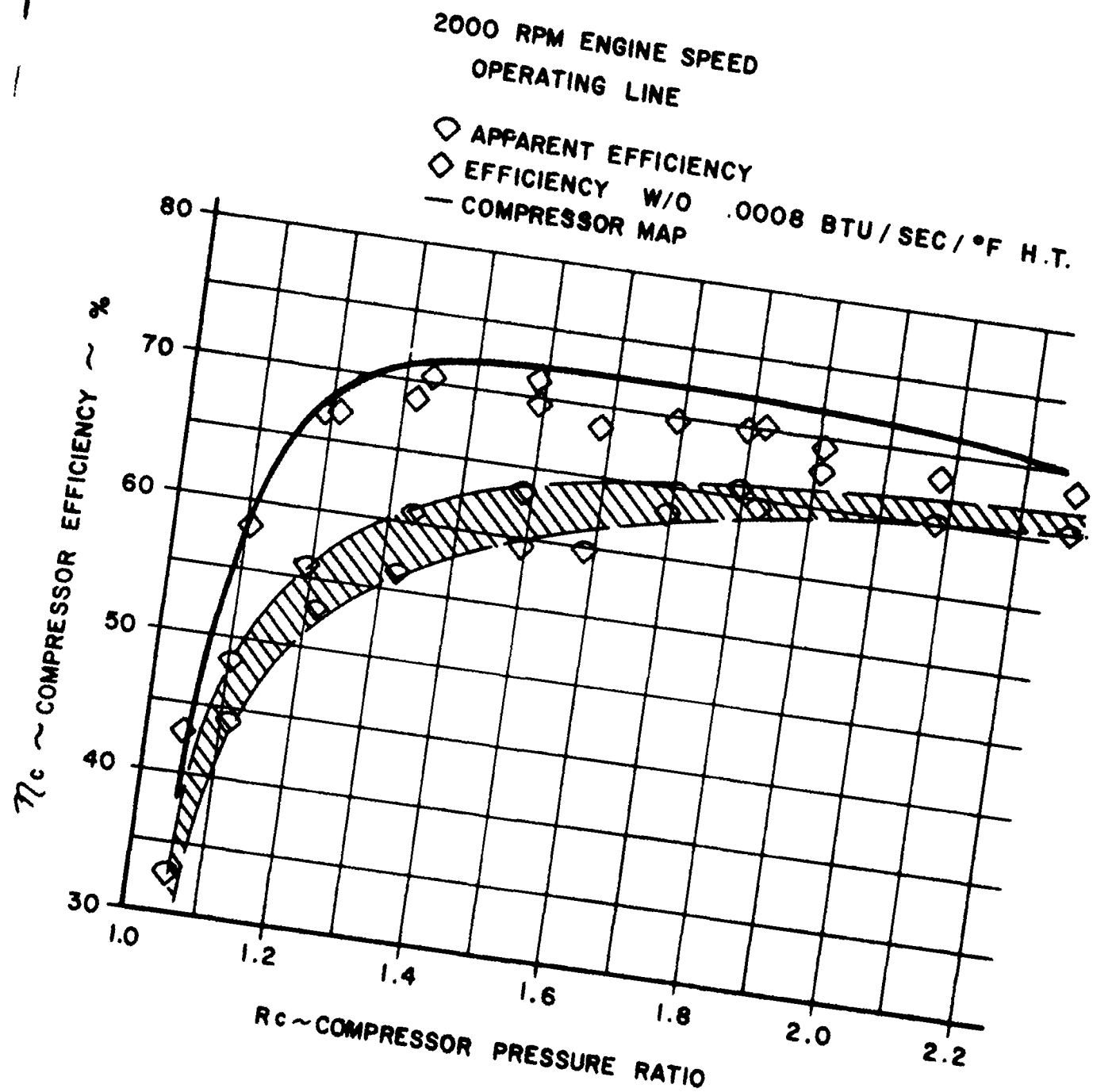


FIGURE 16-
APPARENT EFFECT OF HEAT TRANSFER
ON COMPRESSOR EFFICIENCY
DATA FROM JOHN DEERE 3.9 LITER DIESEL

2500 RPM ENGINE SPEED
 OPERATING LINE

- ◇ APPARENT EFFICIENCY
- ◇ EFFICIENCY W/O .0008 BTU/SEC/°F H.T.
- COMPRESSOR MAP

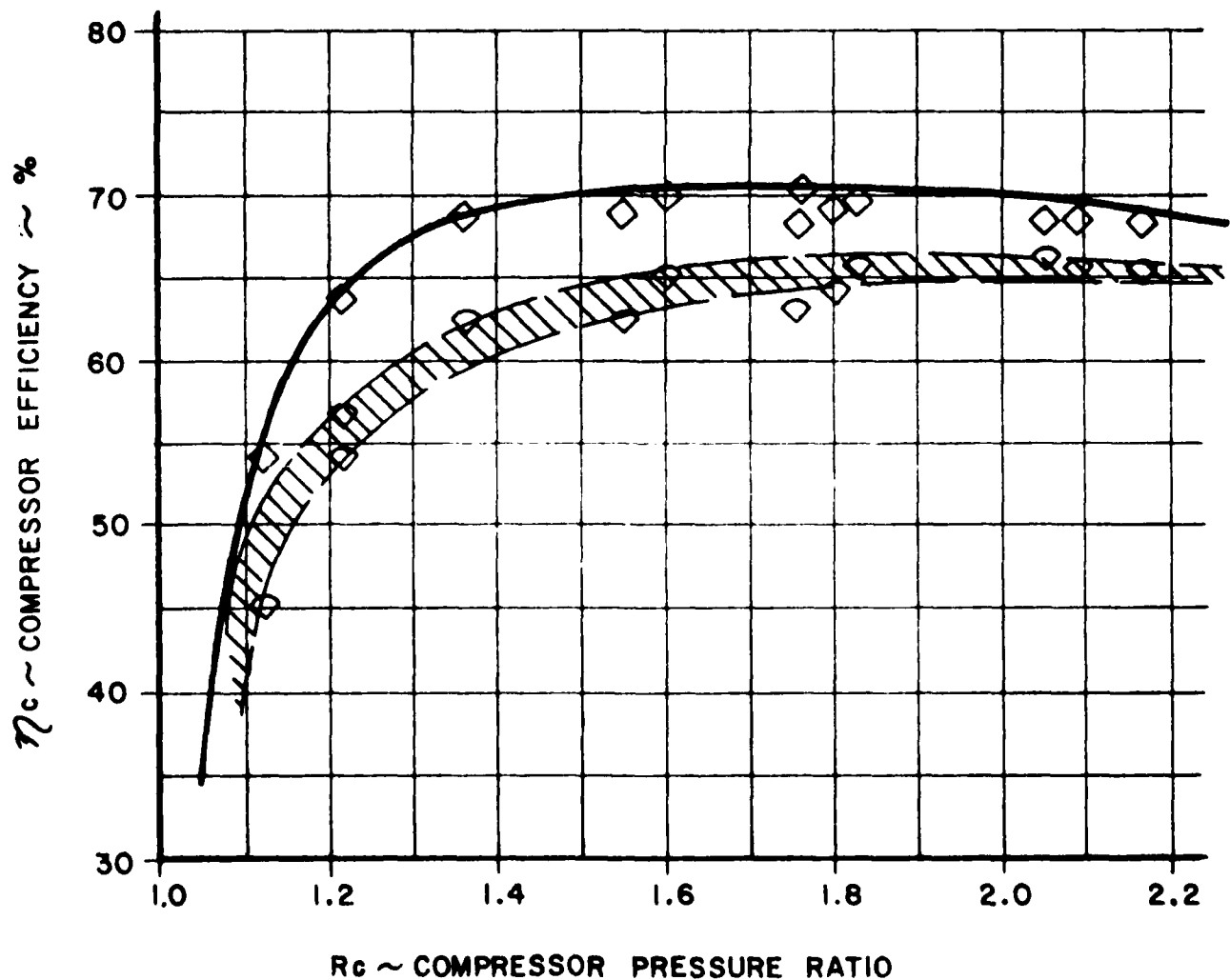
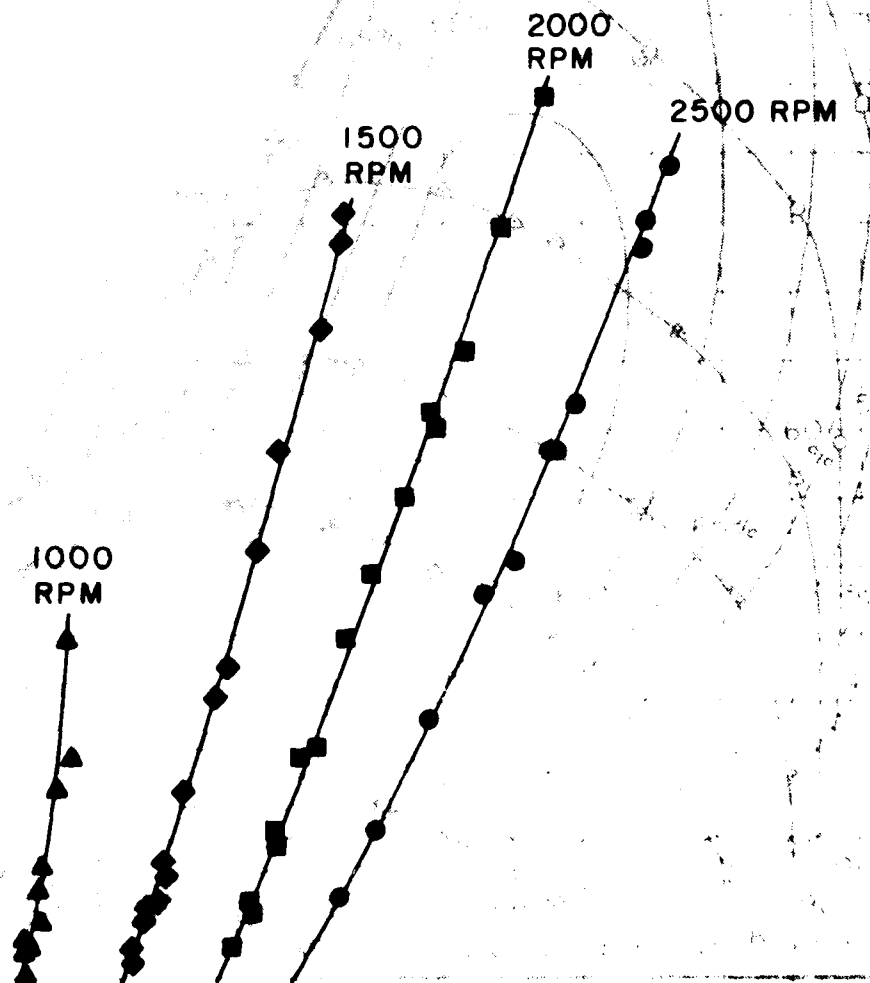


FIGURE 17-
COMPRESSOR MAP WITH 4239T ENGINE SPEED LINES



IV. ROTOR BEARING SYSTEM ANALYSIS AND TEST

The purpose of this portion of the contract was to make a limited demonstration of durability and gain more experience with respect to the ball bearing system which supports the rotor. This phase was to conclude by running a turbocharger for 700 hours. As illustrated in figure 1, both wheels are overhung from the bearings, both of which are full complement (10 balls each) angular contact bearings with a preload spring between them.

ANALYSIS

The original program was to have an analysis made of bearing life by an "outside" consultant or bearing manufacture. This analysis was to consider the influence of speed, radial clearance, inner and outer race curvature, preload, and material hardness. The results of this analysis was to be used as a guide in defining a test program. No source could be found to make the analysis in a timely fashion within the cost constraints of the contract. Therefore, the analysis phase was cancelled.

TEST PLAN

The test plan was defined based on past experience with small instrument bearings in lieu of the "outside" analysis. The objective was to define a series of configurations which would allow speed, radial clearance, preload, number of balls, balance, and type of lubricant to be investigated. Table I lists the test configuration identification and the associated value of the various parameters.

TEST FACILITY

In order to test these various configurations, a bearing shaft test rig facility was fabricated. This facility was a 354 CID, 6 cylinder, diesel engine the exhaust of which was used to drive an Aerodyne turbocharger. The compressor discharge was fed into a plenum which in turn supplied the compressed air to each of 24 bearing shaft test rigs. Each test rig was composed of a bearing and shaft arrangement the same as the turbocharger. On the end of the shaft, where the turbine rotor would be, an air turbine was machined. Figure 18 is a photograph showing the various parts which make up a test rig. A valve was placed between each test rig and the plenum in order to control the flow, and therefore speed, of each rig. The turbocharger, which supplied the pressurized air, was controlled by moving the turbine vanes and bleeding air to ambient at locations where no rigs were installed.

TEST RESULTS

The test rig configurations listed in Table I were built, installed, and run. Bearing failures began to occur after only 10 hours of running. At first it was felt that the failed configurations incorporated parameter combinations which caused the failures. After 30-50 hours all but a few rigs had failed. At this point a detailed investigation of the grinding process revealed that the inner bearing races, which are ground on the shaft, were not accurate. This was actually traced to the dressing of the grinding wheel. The diamond

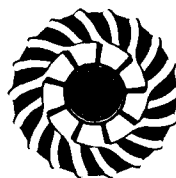
did not travel in a plane intersecting the axis of rotation of the grinding wheel. This resulted in a non-circular dress of the wheel. The local curvature at the point of contact with the balls was almost the same as the ball curvature. This gave a very large contact area which caused frictional wear. The problem was corrected. Also a different grit grinding wheel was procured which gave an improved surface finish. At this point in time, there were only four test rig shafts remaining and it was not feasible to make an additional 24 new shafts in the remaining contract time. These four shafts were ground to a larger radius of curvature than the original rigs; 0.070 as opposed to .067 inch. This increase in radius of curvature reduced the sensitivity of the race being an arc of a "perfect" circle.

The four rigs were built to the following configuration and run for the time indicated. (See Table I for configuration definition).

Config.	Hours run
N2A	312
N8A	456
N1A	408
N/2A	672

At this point 1011 hours had been accumulated on the Aerodyne turbocharger which was supplying the compressed air to the plenum. It was felt that, although the original testing was not complete, the turbocharger had run for well over the 700 hour goal, namely for 1011 hours, without incident. During this time the turbocharger operated at speeds between 70000 and 78000 rpm. The turbocharger was disassembled and inspected. The VATN system was still functional and the bearings were in excellent condition. The turbocharger was subsequently installed on a diesel powered automobile and continued to perform.

TABLE I - Bearing test configuration



Aerodyne Dallas

Test ID	Speed rpm X 10 ³	Radial Cl X 10 ⁻³ in	Inner Trk Curv %	Outer Trk Curv %	Preload LB	Out Of Bal	Hardness Rc	# of Balls	Lube
N1A	120	5	52	52	9	0	61	10	"B"
N2A	↓	8	↓	↓	↓	↓	↓	↓	↓
N3A	↓	11	↓	↓	↓	↓	↓	↓	↓
N4A	90	5	↓	↓	↓	↓	↓	↓	↓
N5A	↓	8	↓	↓	↓	↓	↓	↓	↓
N6A	↓	11	↓	↓	↓	↓	↓	↓	↓
N7A	120	5	↓	↓	5	↓	↓	↓	↓
N8A	↓	8	↓	↓	↓	↓	↓	↓	↓
N9A	↓	11	↓	↓	↓	↓	↓	↓	↓
N10A	↓	5	↓	↓	9	↓	↓	9	↓
N11A	↓	8	↓	↓	↓	↓	↓	↓	↓
N12A	↓	11	↓	↓	↓	↓	↓	↓	↓
N13A	↓	8	↓	↓	5	limit	↓	9	↓
N14A	↓	↓	↓	↓	5	↓	↓	10	↓
N15A	↓	↓	↓	↓	9	↓	↓	9	↓
N16A	↓	↓	↓	↓	9	↓	↓	10	↓
N17A	↓	↓	↓	↓	9	0	↓	10	HUMB
N18A	↓	↓	↓	↓	↓	↓	↓	↓	ISOFLX
N2B	↓	↓	↓	↓	↓	↓	↓	↓	B
N2C	↓	↓	↓	↓	↓	↓	↓	↓	↓
O2A	↓	↓	↓	↓	↓	↓	↓	↓	↓
O17A	↓	↓	↓	↓	↓	↓	↓	↓	HUMB
O18A	↓	↓	↓	↓	↓	↓	↓	↓	ISOFLX

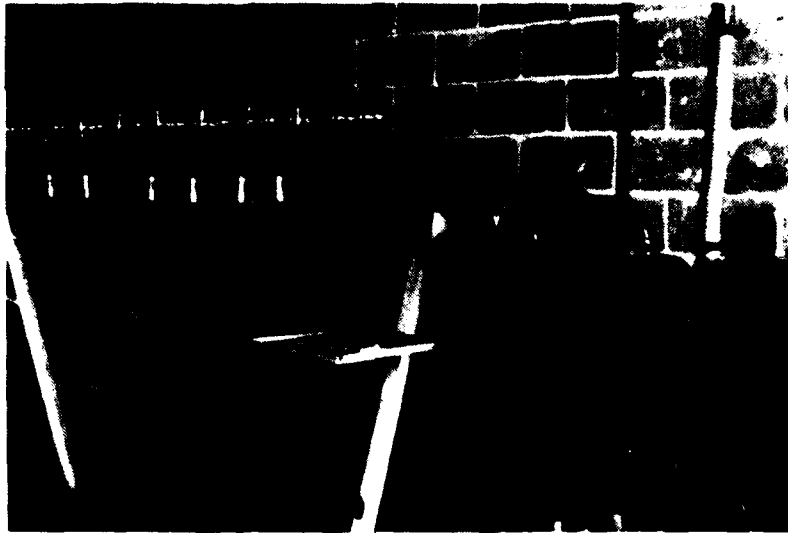


FIGURE 18a - BEARING SHAFT TEST FACILITY

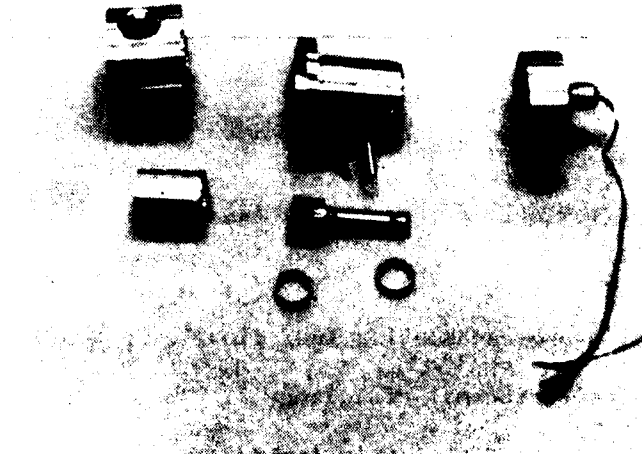


FIGURE 18b - TEST RIG (ONE OF 24)

V. MATH MODEL

A math model more elaborate than that included in the previous contract was generated. Correlations used in the current math model were deduced from data taken on the John Deere 4239T diesel engine.

MODEL GENERATION

First order principles augmented by correlations are used to model the engine. The turbocharger modelling is composed of a compressor map non-dimensionalized in terms of parameters which allow the map to be scaled to different compressor trims. Turbine performance is characterized by a series of maps at each of five turbine vane positions. Heat transfer from turbine to compressor and leakage from turbine to compressor and turbine to ambient can be accounted for in the calculation.

The frictional loss of the engine is expressed in terms of mean effective pressure by the following equation:

$$Fmep = (SK*NE/6)*(1.555 \times 10^{-5} * Imep + 0.011818) + 0.01183 * Imep + 8.797$$

where:

Fmep = friction mean effective pressure — psi

SK = stroke — inches

NE = engine speed — rpm

Imep = indicated mean effective pressure — psi

The difference in pressure between intake and exhaust manifolds ($P_{im} - P_{em}$) is not included in this definition of Fmep. Brake mean effective pressure, BMEP (psi), is expressed as:

$$BMEP = Imep - Fmep + (P_{im} - P_{em})$$

Imep is expressed as:

$$Imep = 1.1225 \times 10^6 * CE * EFF_{ith} / (DS * NE)$$

where:

CE = chemical energy available, fuel flow*lower heating value - Btu/sec

EFF_{ith} = indicated thermal efficiency

DS = engine displacement - cubic inches

P_{im} = intake manifold pressure - psia

P_{em} = exhaust manifold pressure - psia

Indicated thermal efficiency is determined from a correlation which expresses EFF_{ith} as a function of air/fuel ratio and engine speed, (see figure 19). This correlation was derived from 4239T engine test data taken at Aerodyne with the T04 turbocharger.

The exhaust manifold temperature is determined by calculating an ideal combustion temperature and an ideal temperature after expansion to either the full piston stroke change in volume or exhaust manifold pressure, whichever is greater. Two energy losses are assumed to occur which reduces the exhaust manifold temperature below the calculated ideal value. An adjustment is first made to the ideal combustion temperature to account for combustion inefficiency. This is done by arbitrarily assuming a 98% combustion efficiency at the air/fuel ratio where maximum indicated thermal efficiency occurs for a given engine speed, (see figure 19). Then the combustion efficiency is further reduced by assuming that it is proportional to the change in indicated thermal efficiency which occurred due to the air/fuel ratio not being equal to the "max EFF_{ith} " value. The other heat loss term is calculated from heat transfer to the coolant. With these two adjustments, a gas temperature "at the exhaust port" can be calculated. Heat loss via convection and radiation from the exhaust manifold is estimated from basic heat transfer concepts. This adjustment is made to calculate turbine inlet temperature. If heat transfer is assumed to take place between turbo-charger turbine and compressor, the loss is taken prior to the turbine expansion process.

Air mass flow rate through the engine is calculated using a volumetric efficiency which is corrected for the pressure difference across the engine ($P_{im} - P_{em}$). This parameter has been named base volumetric efficiency. For a four cycle engine, volumetric efficiency is defined as:

$$EFFVOL = 3456 \cdot \dot{m}_{chg} / (P_{chg} \cdot DS \cdot NE)$$

where:

$EFFVOL$ = volumetric efficiency

\dot{m}_{chg} = charge mass flow rate - lbm/min

P_{chg} = charge density at intake value - lbm/ft³

DS = displacement - cubic inches

NE = engine speed - rpm

By assuming that there is very little valve overlap and by knowing intake and exhaust manifold pressure the following "first order" correction is made to volumetric efficiency to get base volumetric efficiency:

$$EFFVOL \text{ base} = EFFVOL / (1 - (P_{em}/P_{im} - 1) / (CR - 1))$$

where:

$EFFVOL \text{ base}$ = base volumetric efficiency

P_{em} = exhaust manifold pressure - psia

P_{im} = intake manifold pressure - psia

CR = compression ratio

This relation also does not take into account any tuning effects of the intake or exhaust manifold. Base volumetric efficiency was calculated for the John Deere 4239T engine tested with the T04 turbocharger at Aerodyne. These data were correlated against the square root of intake manifold temperature is proportional to acoustic velocity at the intake valve, (see figure 20).

Smoke and emissions data taken during the previous contract at Southwest Research Institute were correlated. Carbon monoxide (CO) and unburned hydrocarbons (HC) were expressed as volumetric ratio to fuel i.e. parts of CO or HC per million parts of fuel (in a gaseous state). The independent variable for both correlations was chosen as the average temperature of combustion where combustion was assumed to be the ideal constant pressure process. Figures 21 and 22 show linear least square fits of the log of the dependent parameter with the independent parameter. Oxides of nitrogen (NO_x) were also correlated against the average combustion temperature. In this case, the amount of pollutant was expressed as the volumetric ratio to unburned air (parts of NO_2 per million parts of unburned air). A linear least squares function was fitted to the log of the NO_x parameter versus the average combustion temperature, (see figure 23). The Bosch smoke number was obtained from the percent opacity data taken by Southwest Research Institute using the SAE handbook correlated for a 4 inch stack outlet diameter. The independent correlation parameter was chosen to be the ratio of unburned fuel/air. Unburned fuel was estimated in the same manner as combustion inefficiency was accounted for in determining exhaust manifold temperature described previously. Figure 24 shows this correlation.

The entire model involved a multitude of iteration and subiteration loops. The model was programmed in BASIC on a TRS80 computer. Conditions from the previous engine testing with T04 turbocharger were calculated using the math model. Calculations were also made for some of the data points taken from current contract with the Aerodyne turbocharger. Table II lists the comparison between calculated and measured brake specific fuel consumption values for the 4239T engine operating with the T04, fixed area, turbocharger. Table III lists similar data for the Aerodyne turbocharger.

FIGURE 19-
INDICATED THERMAL EFFICIENCY CORRELATION
 (FROM ENGINE TEST AT AERODYNE WITH T04 ON 4239T)

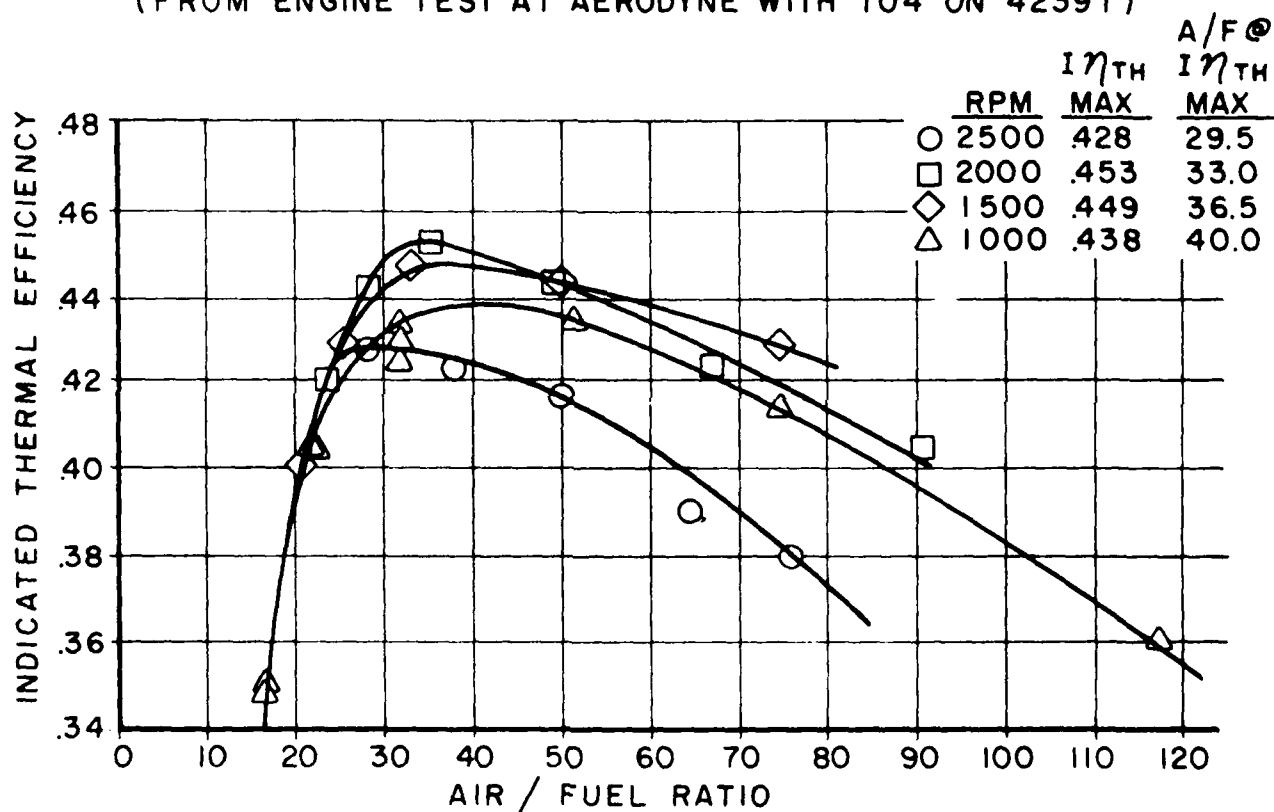


FIGURE 20-
BASE VOLUMETRIC EFFICIENCY CORRELATION
 (FROM ENGINE TEST AT AERODYNE WITH T04 ON 4239T)

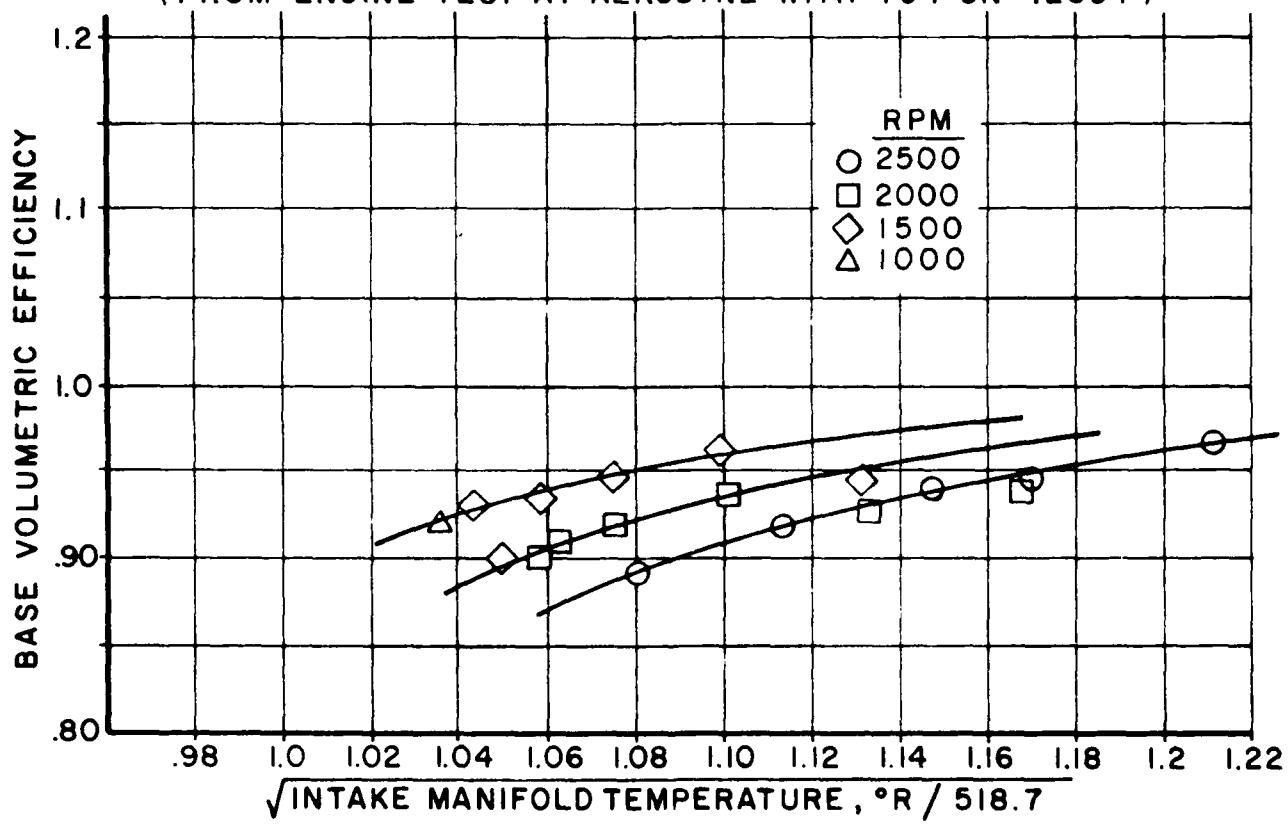


FIGURE 21- CO CORRELATION

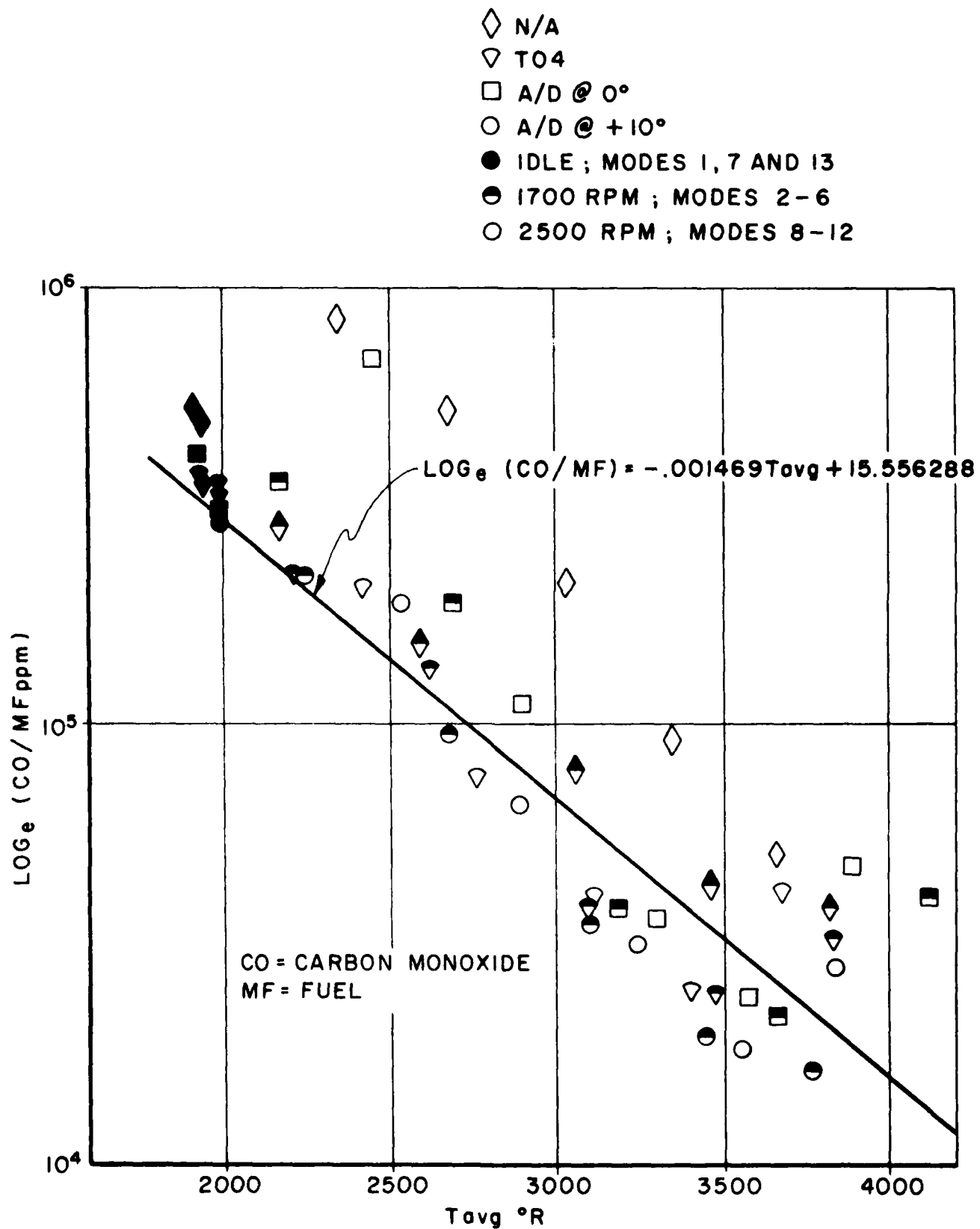


FIGURE 22- HC CORRELATION

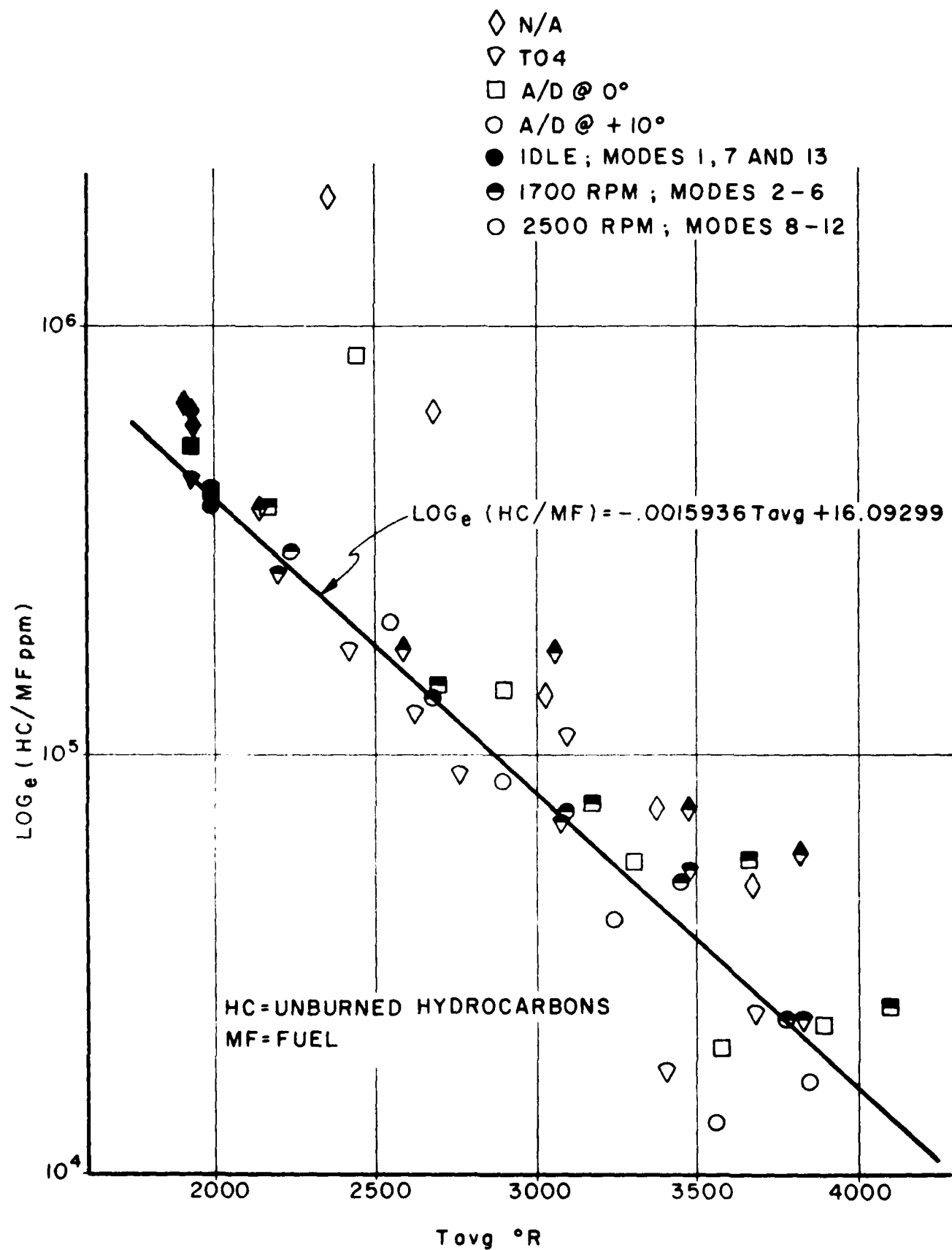


FIGURE 23- NO₂ CORRELATION

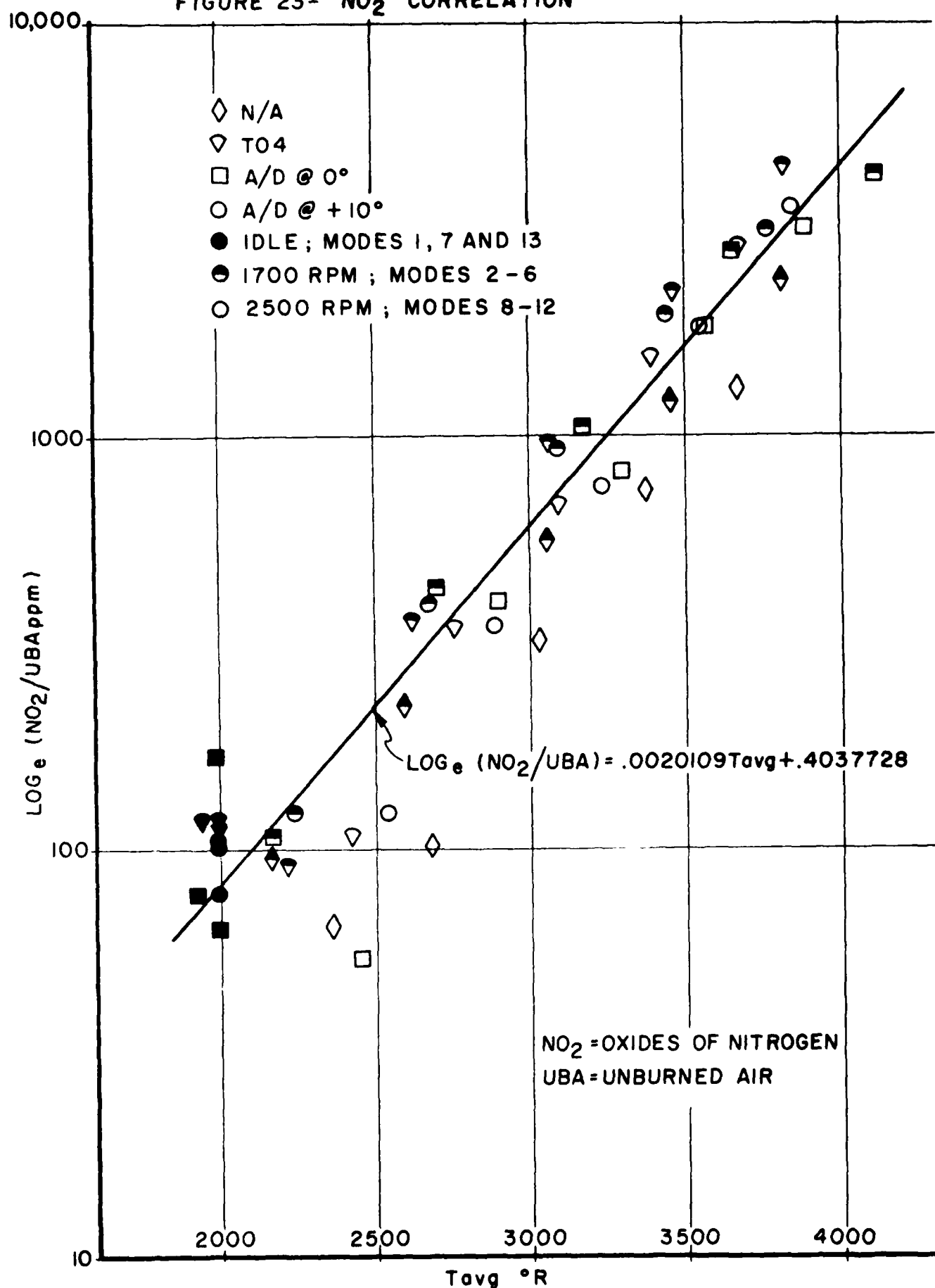


FIGURE 24 - BOSCH SMOKE NUMBER CORRELATION
BASED ON
SOUTHWEST RESEARCH INST. DATA

<u>SYMBOL</u>	<u>TURBOCHARGER</u>
○	T04
□	A/D @ 0°
◇	A/D @ +10°

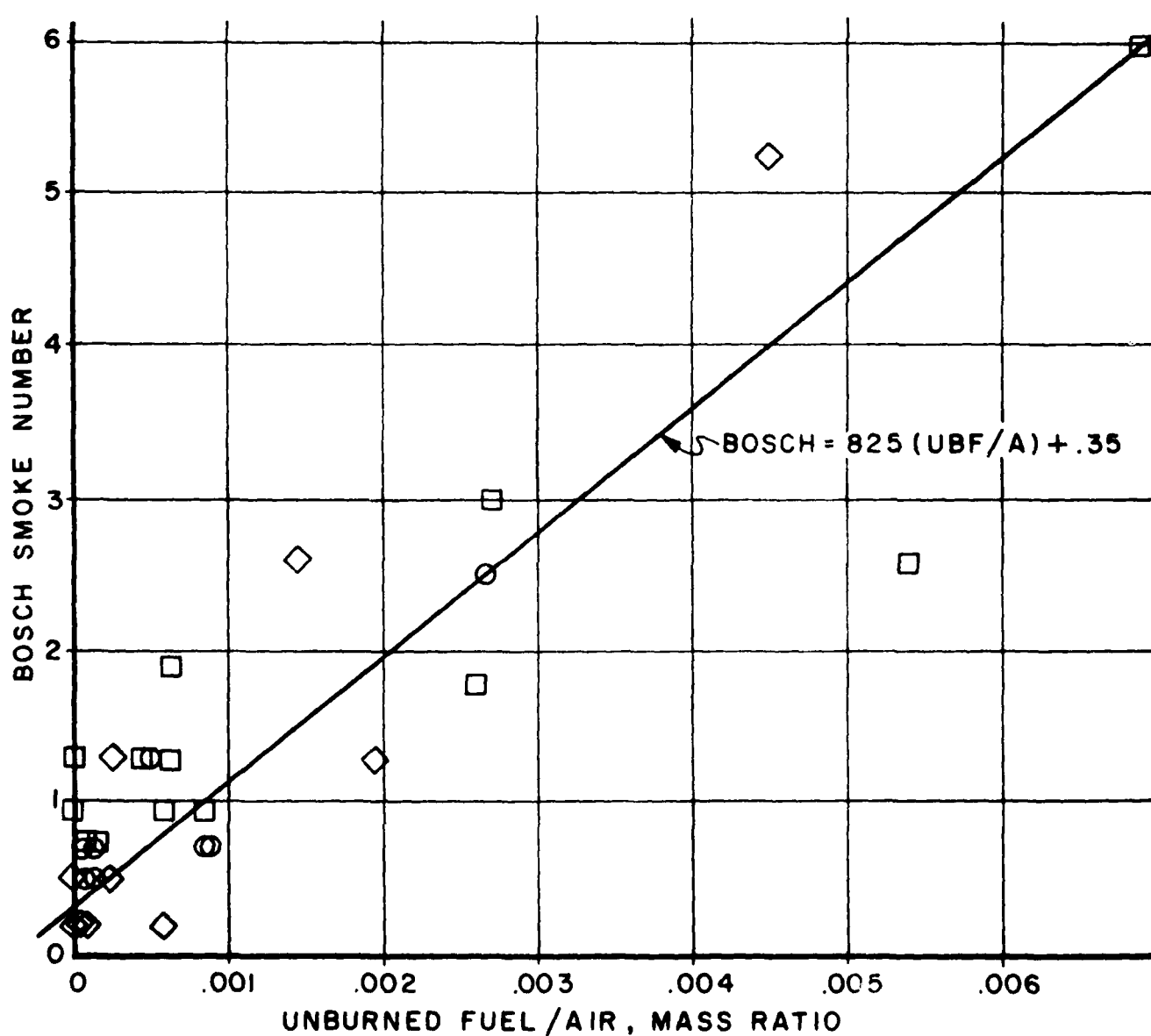


TABLE II - Calculated and measured BSFC values for fixed area turbocharger

Engine Speed (rpm)	Load (ft lb)	BSFC (lb/hp-hr)		
		meas	calc	error
2500	197	.414	.4153	+0.3%
2500	99	.504	.5034	-0.1%
1500	232	.401	.4250	+6.0%
1500	173	.393	.4059	+3.3%
1500	122	.409	.4104	+0.3%
1500	61	.509	.5079	-0.2%

avg. = +1.6%

TABLE III - Calculated and measured BSFC values for VATN turbocharger

Engine Speed (rpm)	Load (ft lb)	BSFC (lb/hp-hr)		
		meas	calc	error
2500	194	.400	.4303	+7.6%
2500	195	.400	.4093	+2.3%
2500	98	.479	.4981	+4.0%
2500	97	.500	.5105	+2.1%
1500	216	.379	.4181	+10.3%
1500	216	.377	.3870	+2.6%
1500	108	.412	.4151	+0.7%
1500	108	.407	.4198	+3.1%
1500	108	.409	.4168	+1.9%

avg. = +3.8%

The model predicts the BSFC to be 3.8% too high for the VATN unit and 1.6% high for the fixed area unit. The additional error for the VATN turbocharger may be due to the volumetric efficiency algorithm not properly accounting for the difference between intake and exhaust manifold pressure. This, in turn, causes the calculated air/fuel ratio to be in error. Many of the calculation procedures depend on air/fuel ratio, including the indicated thermal efficiency calculation.

FIGURE 25-
CALCULATED 4239T DEERE ENGINE
FUEL FLOW FOR 13 MODE FEDERAL
DIESEL EMISSIONS CYCLE

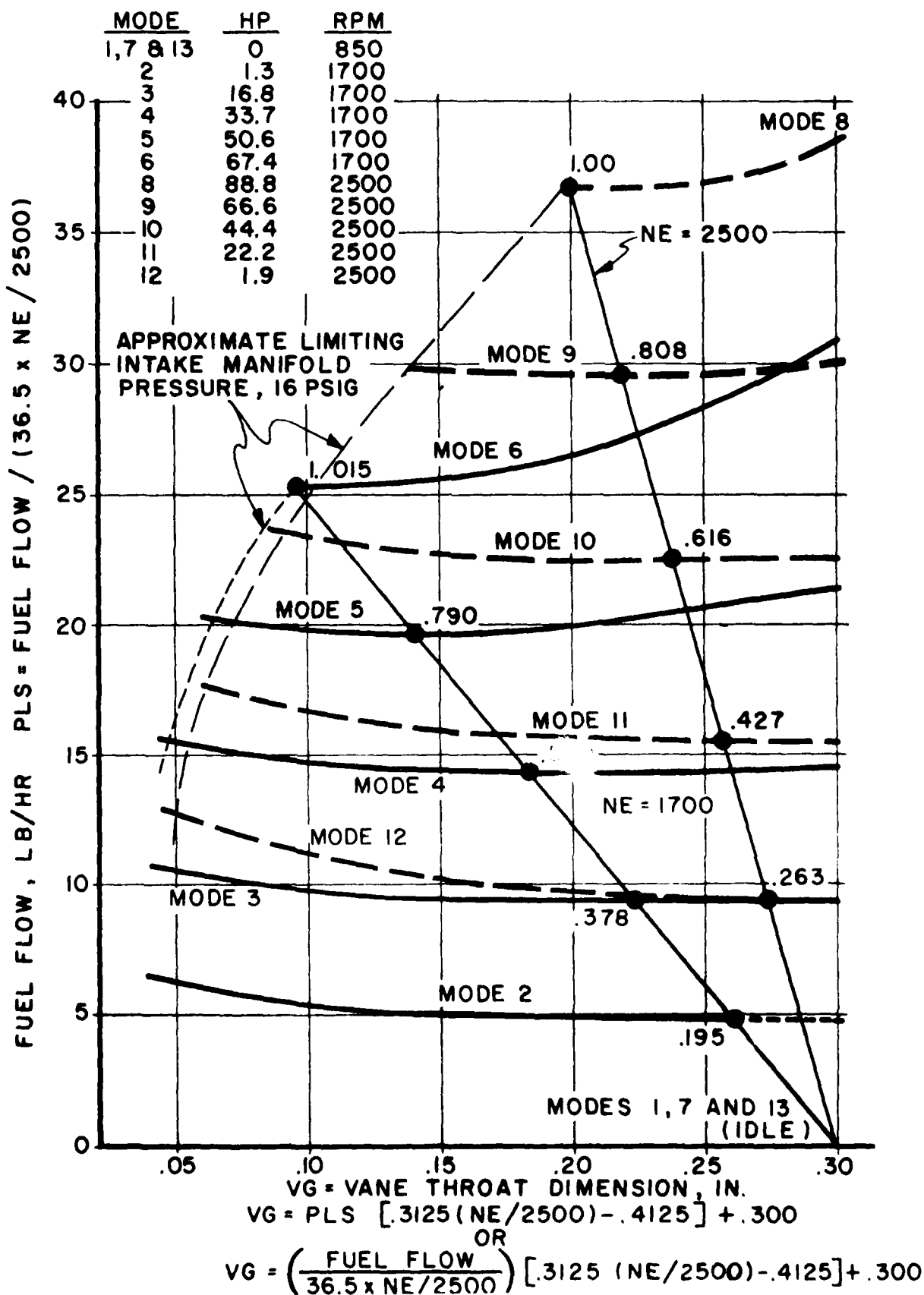


FIGURE 26-
CALCULATED 4239T DEERE ENGINE
HYDROCARBON EMISSIONS FOR 13 MODE FEDERAL
DIESEL EMISSIONS CYCLE

MODE	HP	RPM
1, 7 & 13	0	850
2	1.3	1700
3	16.8	1700
4	33.7	1700
5	50.6	1700
6	67.4	1700
8	88.8	2500
9	66.6	2500
10	44.4	2500
11	22.2	2500
12	1.9	2500

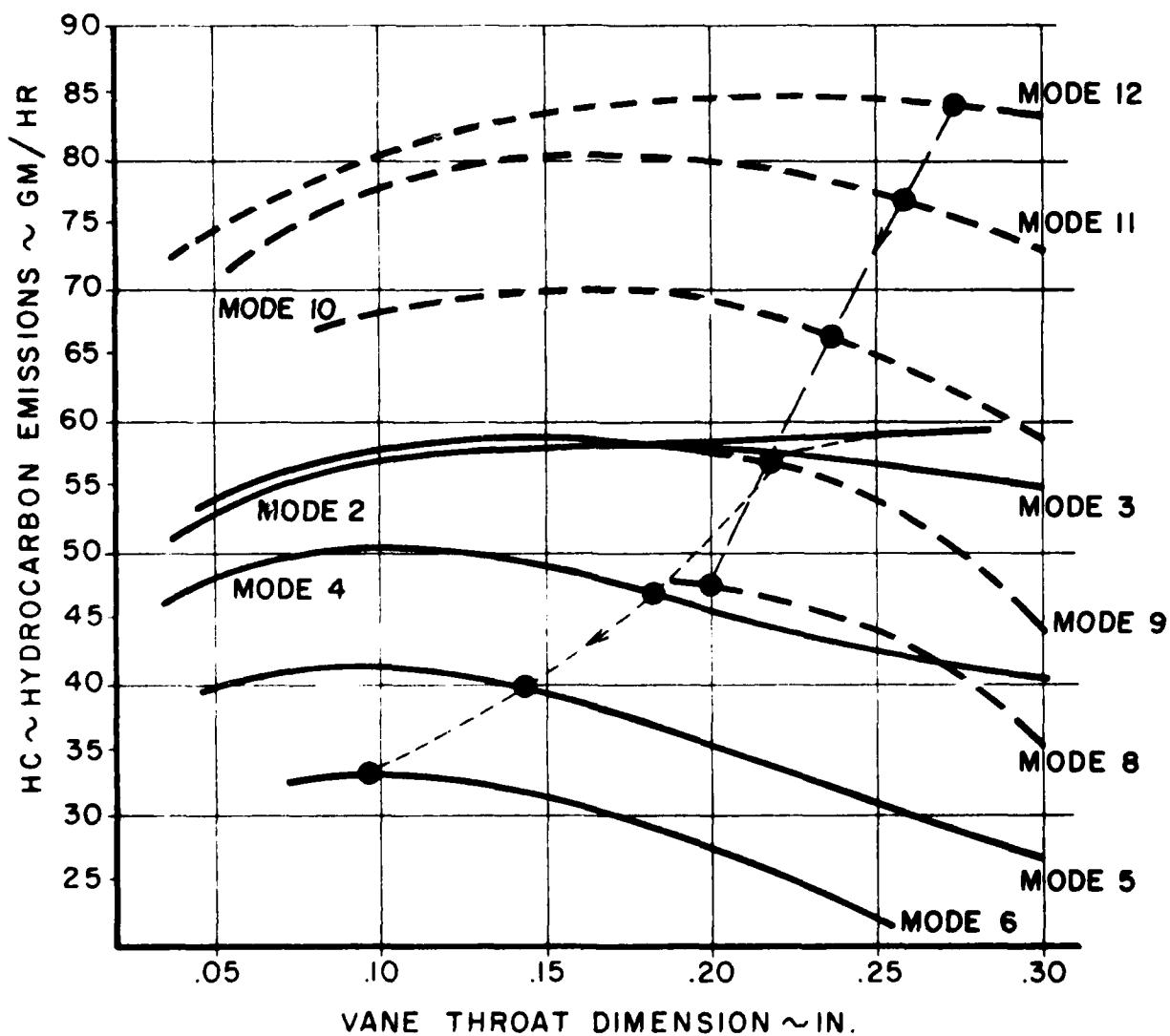
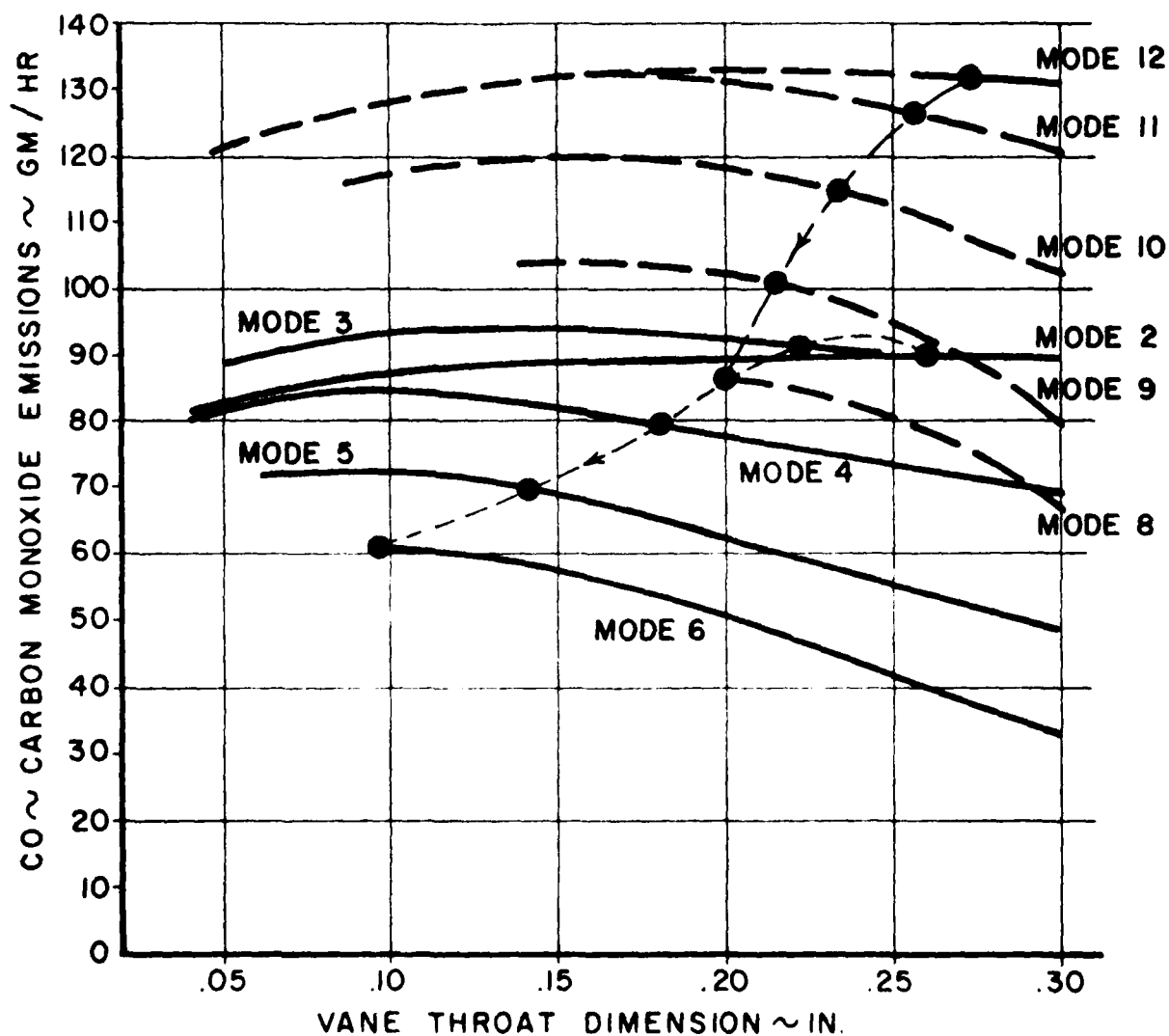


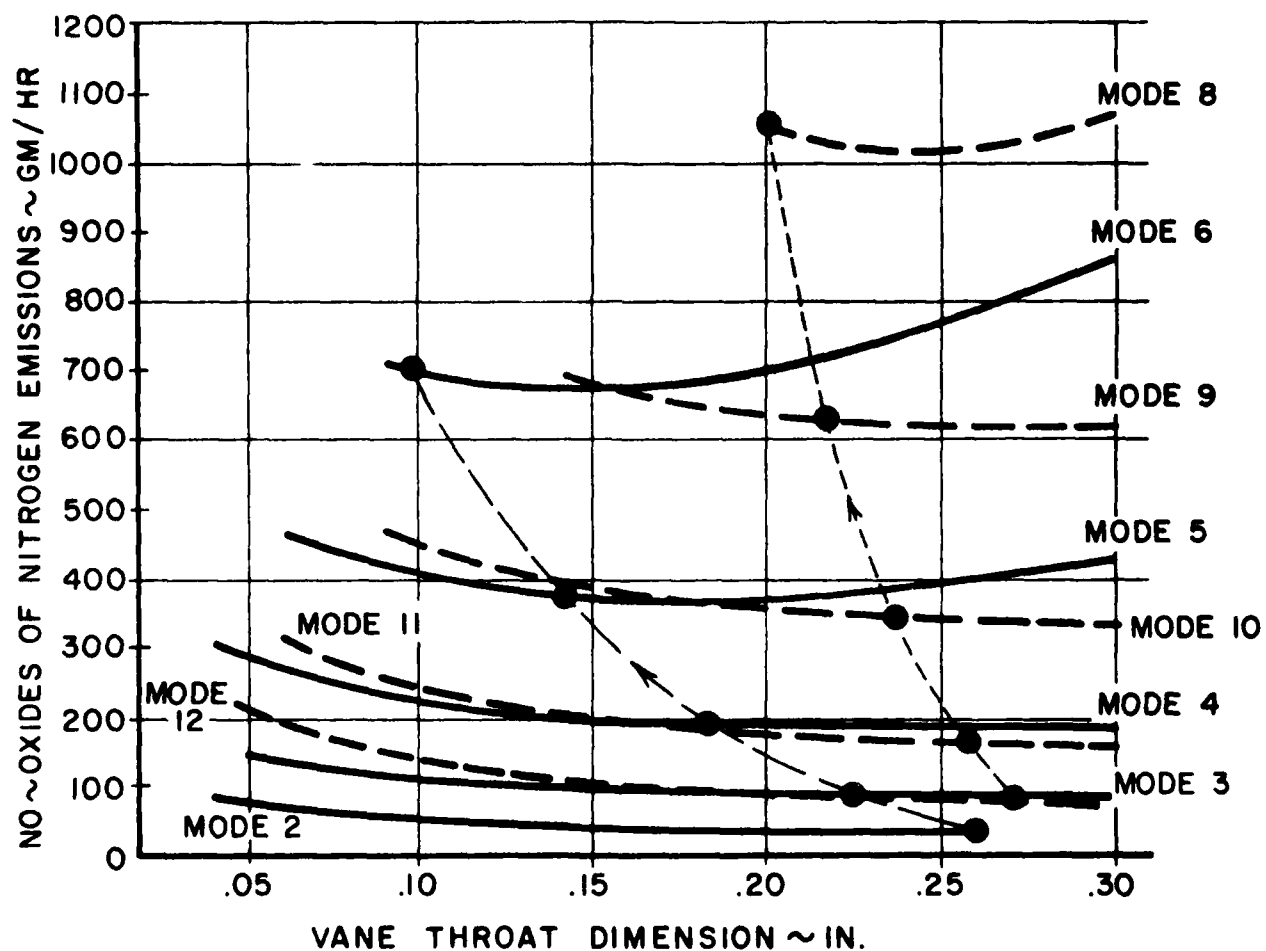
FIGURE 27-
CALCULATED 4239T DEERE ENGINE
CARBON MONOXIDE EMISSIONS FOR 13 MODE FEDERAL
DIESEL EMISSIONS CYCLE

MODE	HP	RPM
1, 7 & 13	0	850
2	1.3	1700
3	16.8	1700
4	33.7	1700
5	50.6	1700
6	67.4	1700
8	88.8	2500
9	66.6	2500
10	44.4	2500
11	22.2	2500
12	1.9	2500

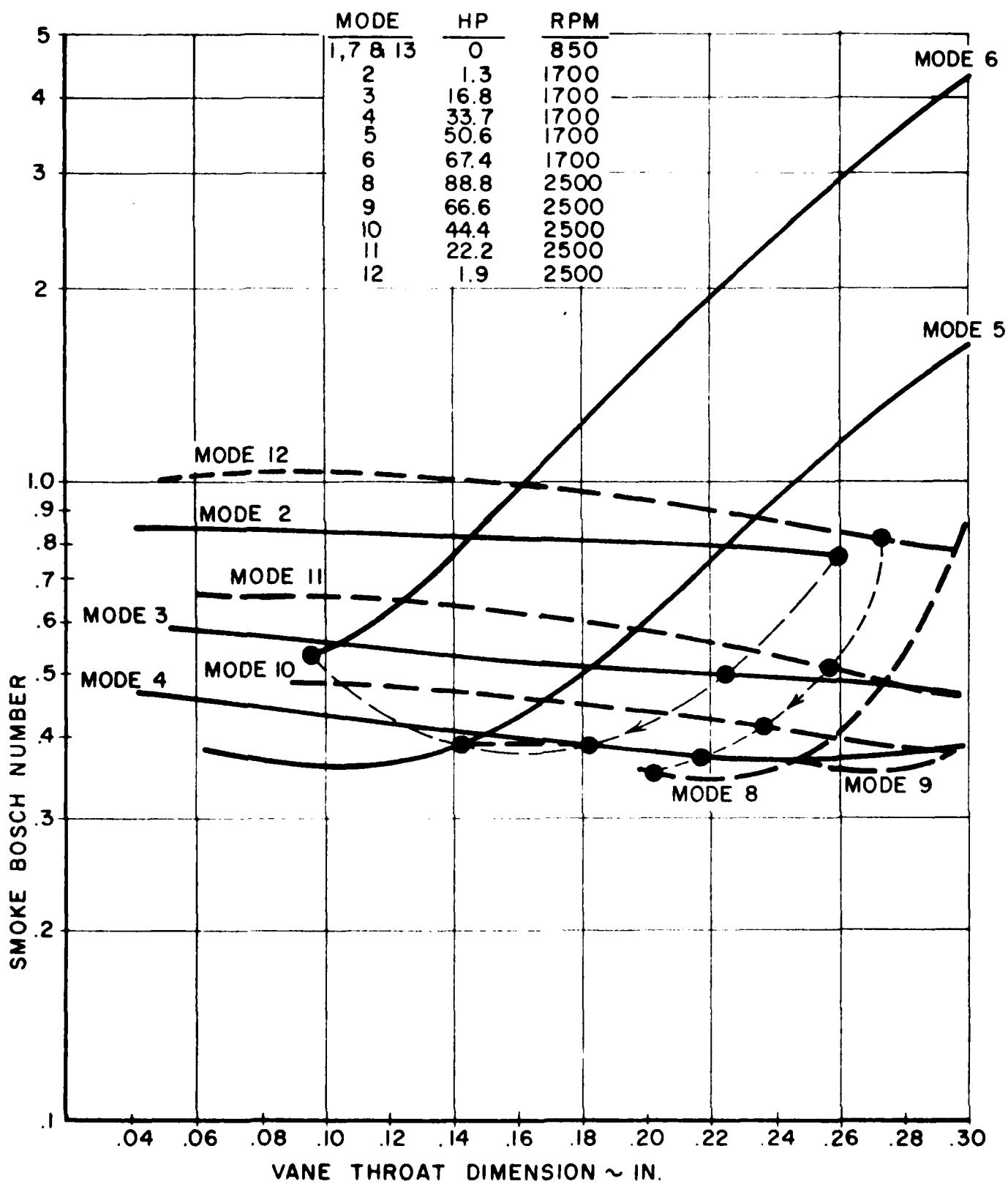


**FIGURE 28- CALCULATED 4239T DEERE ENGINE
OXIDES OF NITROGEN FOR 13 MODE FEDERAL
DIESEL EMISSIONS CYCLE**

MODE	HP	RPM
1, 7 & 13	0	850
2	1.3	1700
3	16.8	1700
4	33.7	1700
5	50.6	1700
6	67.4	1700
8	88.8	2500
9	66.6	2500
10	44.4	2500
11	22.2	2500
12	1.9	2500



**FIGURE 29- CALCULATED 4239T DEERE ENGINE
SMOKE BOSCH NUMBER FOR 13 MODE FEDERAL
DIESEL EMISSIONS CYCLE**



MODEL APPLICATION

13 Mode Federal Diesel Emissions Cycle

The math model described above was used to generate John Deere 4239T engine fuel consumption, smoke, and emissions data for the 13 operating modes of the federal diesel emissions cycle. The mode definitions and calculation procedures were taken from the 1981 SAE Handbook, pages 25.20 and 25.21 (SAE J1003). At each of the 13 modes the model was executed at various vane throat values. The maximum firing pressure limit was approximated by constraining the intake manifold pressure to values less than 16 psig. Figure 25 presents the calculated fuel flow rates for each of the modes as a function of vane throat. The power output and engine speed are also called out in figure 25 for each mode. Figures 26, 27, and 28 show unburned hydrocarbons, carbon monoxide, and oxides of nitrogen in a similar fashion to figure 25. Bosch smoke number is shown in figure 29.

Control Strategy

A control strategy was defined for the 4239T engine operating over the 13 mode federal diesel cycle. To define the control operation, it was assumed that fuel flow per revolution is proportional to throttle position. A control schedule was derived which would define the desired vane throat as a function of engine speed and throttle position.

$$VT = PLS (0.3125 (NE/NE_{max}) - 0.4125) + 0.300$$

where:

VT = vane throat - inches

PLS = throttle position as a fraction of full travel

NE = engine speed - rpm

NE_{max} = maximum rated engine speed - rpm

This control schedule was thought to be relatively simple, involving only two independent variables: engine speed and throttle position. The mathematical function was derived so as to pass the control schedule through, or near, the minimum fuel flow rate points for each mode. The resulting operating lines are shown in figures 25 through 29. Weighted average values of brake specific fuel consumption and emissions were calculated using the aforementioned SAEJ1003 procedure.

The mode operating conditions are shown in Table IV below.

Table IV - Speed-Load Schedule of 13-Mode Federal
Diesel Emission Cycle

<u>Mode</u>	<u>Speed</u>	<u>Torque</u>
1	IDLE	--
2	S	$0.02 \times T_m$
3	S	$0.25 \times T_m$
4	S	$0.50 \times T_m$
5	S	$0.75 \times T_m$
6	S	T_m
7	IDLE	--
8	S_m	T
9	S_m	$0.75 \times T$
10	S_m	$0.50 \times T$
11	S_m	$0.25 \times T$
12	S_m	$0.02 \times T$
13	IDLE	--

where:

T_m - Rated Torque

S_m - Rated Speed

T - Highest Torque at Rated Speed

S - Highest Speed at Rated Torque

Table V - lists the emissions and fuel consumption data calculated for the Aerodyne turbocharger controlled to the schedule shown in figures 25 through 28.

Table V - 13 Mode Emissions Calculated For Aerodyne Turbocharger With Controller

For Idle Modes (1, 7 & 13) Mass Flows are:

HC = 28.7 GM/HR CO = 42.73 GM/HR NO2 = 12.04 GM/HR

Fuel = 1.76 LB/HR

Brake Specific Emissions And Fuel Consumption For Non-Idle Modes

Mode	BSHC GM/HP-HR	BSCO GM/HP-HR	BSNO2 GM/HP-HR	BSFC LB/HP-HR
2	23.74	36.40	15.04	2.071
3	3.38	5.46	4.96	0.558
4	1.40	2.37	5.54	0.428
5	0.80	1.42	7.24	0.389
6	0.53	0.96	9.99	0.375
8	0.47	0.87	12.84	0.415
9	0.80	1.42	9.88	0.448
10	1.50	2.57	7.64	0.508
11	3.27	5.39	7.52	0.690
12	18.58	29.29	18.67	2.281

Weighted Avg Values:

1.60 2.65 9.47 0.510

The math model was also used to calculate the same data for the T04 turbo-charger. Table VI shows the results of the calculations. Table VII lists the measured 13 mode data for the T04 turbocharger. This data was measured at Southwest Research Institute as part of the previous contract.

Table VI - 13 Mode Emissions Calculated For T04 Turbocharger

For Idle Modes (1, 7 & 13) Mass Flows Are:

HC = 28.7 GM/HR CO = 32.73 GM/HR NO₂ = 12.04 GM/HR

Fuel = 1.76 LB/HR

Brake Specific Emissions And Fuel Consumption For Non-Idle Modes

Mode	BSHC GM/HP-HR	BSCO GM/HP-HR	BSNO ₂ GM/HP-HR	BSFC LB/HP-HR
2	24.82	36.80	15.04	2.091
3	3.46	5.58	4.79	0.561
4	1.35	2.31	5.29	0.432
5	0.70	1.25	7.16	0.403
6	0.41	0.77	10.11	0.407
8	0.48	0.89	12.66	0.418
9	0.80	0.80	9.85	0.451
10	1.46	2.51	8.08	0.515
11	3.35	5.51	7.76	0.696
12	18.74	29.55	20.15	2.323

Weighted Avg Values:

1.57 2.50 9.49 0.520

Table VII-13 Mode Emissions Measured For T04 Turbocharger

For Idle Modes (1, 7 & 13) Mass Flows Are:

HC = 19.65 GM/HR CO = 33.73 GM/HR NO2 = 12.12 GM/HR
 Fuel = 1.76 LB/HR

Brake Specific Emissions And Fuel Consumption For Non-Idle Modes

Mode	BSHC GM/HP-HR	BSCO GM/HP-HR	BSNO2 GM/HP-HR	BSFC LB/HP-HR
2	33.17	55.96	16.72	4.054
3	2.25	3.66	4.61	0.562
4	0.99	1.09	5.56	0.431
5	0.71	0.65	7.78	0.396
6	0.45	1.21	14.72	0.393
8	0.34	1.15	11.24	0.418
9	0.26	0.73	8.34	0.449
10	1.82	1.27	5.49	0.515
11	1.98	3.43	5.32	0.717
12	29.44	70.56	19.98	5.526

Weighted Avg Values:

1.16 2.00 9.28 0.522

By comparing corresponding values in Table VI & VII an assessment of how well the math model compares to measured values can be made for the fixed area turbocharger. The worst agreement was between calculated and measured BSHC values; the best was BSFC. Also, the trends of all the parameters agree rather well with the measured data. A relative comparison between the Aerodyne turbocharger, operating to the previously discussed control schedule, and the T04 can be made from Tables V and VI. As shown in section III, the engine test data indicated an average improvement of 4% in BSFC of the Aerodyne turbocharger as compared to the T04. On the other hand, the math model overestimates fuel flow by 2% for the VATN unit as compared to the T04. Therefore, the calculated "13 mode" BSFC values only show a 2% improvement rather than the expected 4%. The BSHC is higher for the VATN turbocharger while BSCO and BSNO₂ are reduced. An overall emissions comparison is sometimes made using the sum of BSHC and BSNO₂. This value is essentially the same for both turbochargers. By comparing calculated results it can be concluded that the simple control schedule used for the VATN turbocharger will give improved fuel economy as compared to the fixed area T04.

Much more complicated control strategies could be developed which would take into consideration the engines coolant temperature and barometric

conditions. This approach is beyond the scope of this contract, but could give additional improvements.

A control system was built that sensed throttle position and engine speed. The analog circuit output was a "desired" position to a stepping motor which was connected to the VATN control rod. Bench tests of the unit showed that the stepping motor could not respond fast enough. Full travel required 3.0 seconds which was too long a time to justify any further development expenses. Therefore, the hardware phase was stopped. It is felt that the best way to control the VATN system is through a pneumatic driver (piston and spring) with the difference in pressure across the piston being a "leak" to one side of the piston. The piston would be sized to give the proper force to the VATN control rod.

Driving Cycle Simulation (LA4)

In order to use the new math model to estimate results of an automobile operating over the federal driving cycle, it was necessary to generate a math model which would calculate the engine load and speed. Also, an abbreviation of the full 1320 seconds was necessary in order to make the problem manageable. Southwest Research Institute provided an approximation to the LA4 driving cycle. The approximation was made up of nine modes. A VW diesel Rabbitt was chosen as the automobile. Physical characteristics of the automobile and drive line were taken from "Road and Track" magazine and are as follows:

- frontal area = 16.575 ft^2
- weight = 2200 lbm
- max engine speed = 5200 rpm
- gear ratios were 3.76, 1.94, 1.29, and .76 for 1st through 5th gear
- engine speed/car velocity ratio (rpm/mph) of 46

The N/V value in the open literature is 46. A value of 35 was used for this analysis. It was felt that this represents the lowest value reasonable. Even this value requires a very responsive turbocharged engine. A description of the nine modes and associated engine operating conditions is given in Table VIII.

The performance of three engines was estimated using the new math model and the speed and power requirements shown in Table VIII. Engine A represents the current 1.47 liter engine turbocharged to a maximum intake manifold pressure of 1.82 atmosphere absolute pressure, a value assumed to represent contemporary automotive diesel engine. Engine B is a normally aspirated, 2.62 liter engine. Engine C has a displacement of 1.08 liters. The displacement for engines B and C were determined by requiring the power output, at mode 9 conditions, to be equal to that of engine A. For this determination all three engines were assumed to have an air/fuel ratio of 20. Engine C reflects future diesel engine intake manifold pressure level; a value of 3.18 atmosphere (abs) was selected. The turbine vane position controller was assumed to be the same as the one previously used for the "13 mode"

analysis. Figure 30 shows the brake specific fuel consumption (BSFC) as a function of vane throat for each of the nine modes approximating the LA4 driving cycle. Similar data for engine C is shown in figure 31. The "X" symbol indicates the vane position to which the controller moves for each mode. Recall this vane position (throat) is dependent on throttle position and engine speed. Table IX, X and XI list the vane position (VG), BSFC, horsepower, engine speed, and fraction of total fuel usage (%fuel) for each of the nine modes for engine A, B, and C respectively. These tables also show the overall miles per gallon, mpg. It can be seen that the economy is improved 51 percent by replacing a normally aspirated, 2.62 liter engine with a turbocharged engine of equivalent performance. An additional 14 percent improvement can be realized by further reducing the engine size and appropriately increasing the boost level. This estimated performance for engine C also included the effect on indicated thermal efficiency of reducing the compression ratio from 23 to 12. This was done to maintain a reasonable peak firing pressure. This factor was determined from Taylor's "The Internal Combustion Engine in Theory and Practice".

Generator Set Application

In the past, turbocharged diesel engines have not been used to drive Army generator sets because of the requirement that the gen set be able to go from zero to full load while maintaining frequency. Turbocharger "lag" was the source of the problem. The VATN feature can eliminate this problem. This allows smaller, turbocharged diesel engines to replace normally aspirated engines which, in turn, will result in reduced fuel consumption. Using electrical generator efficiency data and fuel consumption data supplied by the Army, the math model was used to estimate potential fuel savings which could be realized by replacing the six cylinder, normally aspirated, 298 CID, diesel engine used to drive a 30KW generator set with a four cylinder, turbocharged, 226 CID, engine. A 0.95 multiplying factor on the indicated thermal efficiency and a 1.10 factor on friction loss enabled the model to predict the current 15KW and 30KW fuel consumption values as measured during the Mil. std. 705 test cycle. Mil. std. 705 duty cycle is as follows:

- 4 hours at zero load
- 24 hours at 25% load (15.5hp)
- 24 hours at 50% load (27.2hp)
- 24 hours at 75% load (38.2hp)
- 24 hours at 100% load (49.1hp)

Ambient conditions were 60°F and 29.92 "Hg". The engine speed is a constant 1800 rpm. The calculated and measured fuel usage values were 126.2 gal and 130.0 gal for the 15KW unit and 227.4 gal and 222.9 gal for the 30KW unit. In terms of error, the 15KW error was -2.9% and the 30KW error was +2.0%.

A 226 CID, 4 cylinder engine was selected to replace the 6 cylinder engine because the engine has been designed to be turbocharged. An air/fuel ratio

of 28 was assumed at full power. It was felt that this is a conservative value which would give good BSFC and no smoke. The resulting compressor pressure ratio was 1.36. Three control strategies were assumed. Control strategy A assumed that the turbocharger pressure ratio, and therefore speed, would be held constant at 1.36. Strategy B held the pressure ratio at 1.36 down to the 25 percent load point. At loads below 25 percent, the vanes were held fixed. It was felt that this would improve the adverse pressure difference across the engine at zero load. The third strategy, C, was similar to B except that the vanes were held fixed from 50% load down to no-load. Table XII compares the fuel consumption of each of the three strategies for the Mil. std. 705 duty cycle. In order to assess the acceptability of allowing the turbocharger speed to drop at low loads (strategies B and C), an instantaneous air/fuel ratio was calculated using the full load fuel flow rate and the no-load air flow rate. This should be the worst condition possible. Table XII also lists these instantaneous values and the engine pressure difference which is exhaust manifold pressure less intake manifold pressure. From these results it is felt that the Aerodyne VATN turbocharger could be employed to reduce the 30KW gen set fuel consumption by 8 to 10 percent of current values. Also the turbocharger vanes could remain in a fixed position below 25 to 50% load without adversely affecting the gen set response.

Table VIII - Nine mode approximation to LA4 driving cycle

Mode #	Gear	Vel mph	Accel mph/sec	Power hp	Eng spd rpm
1	0	0	0	0	850
2	2	20	0	1.475	1786
3	2	25	0	2.148	2233
4	3	30	0	3.023	1782
5	4	35	0	4.141	1363
6	4	45	0	7.269	2010
7	4	55	0	11.856	2456
8	1	15	2.5	12.108	2597
9	2	25	2.5	20.720	2233

FIGURE 30-
ENGINE A BSFC AS A FUNCTION
OF VANE THROAT FOR LA4

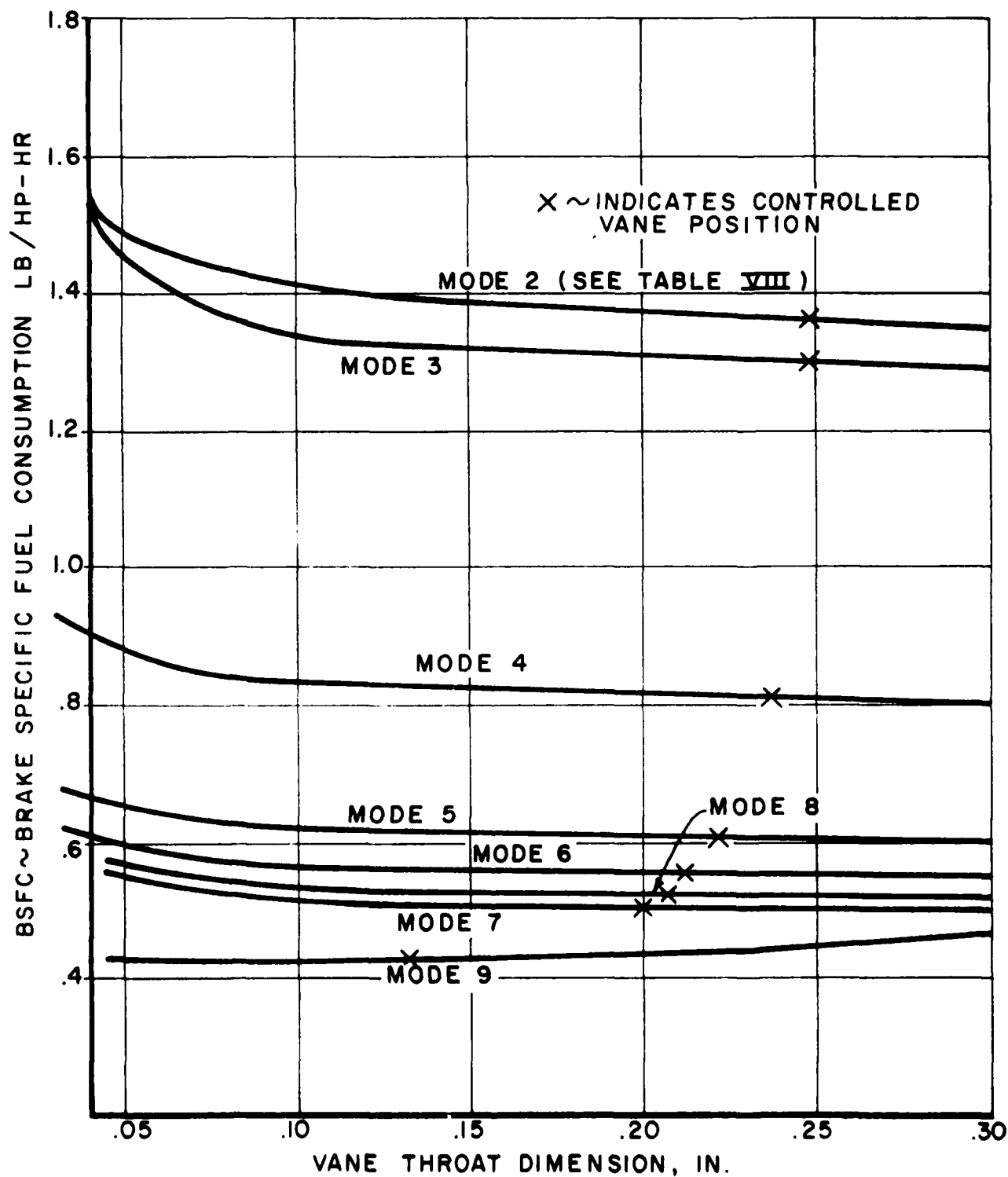


FIGURE 31-
ENGINE C BSFC AS A FUNCTION OF VANE THROAT FOR LA4

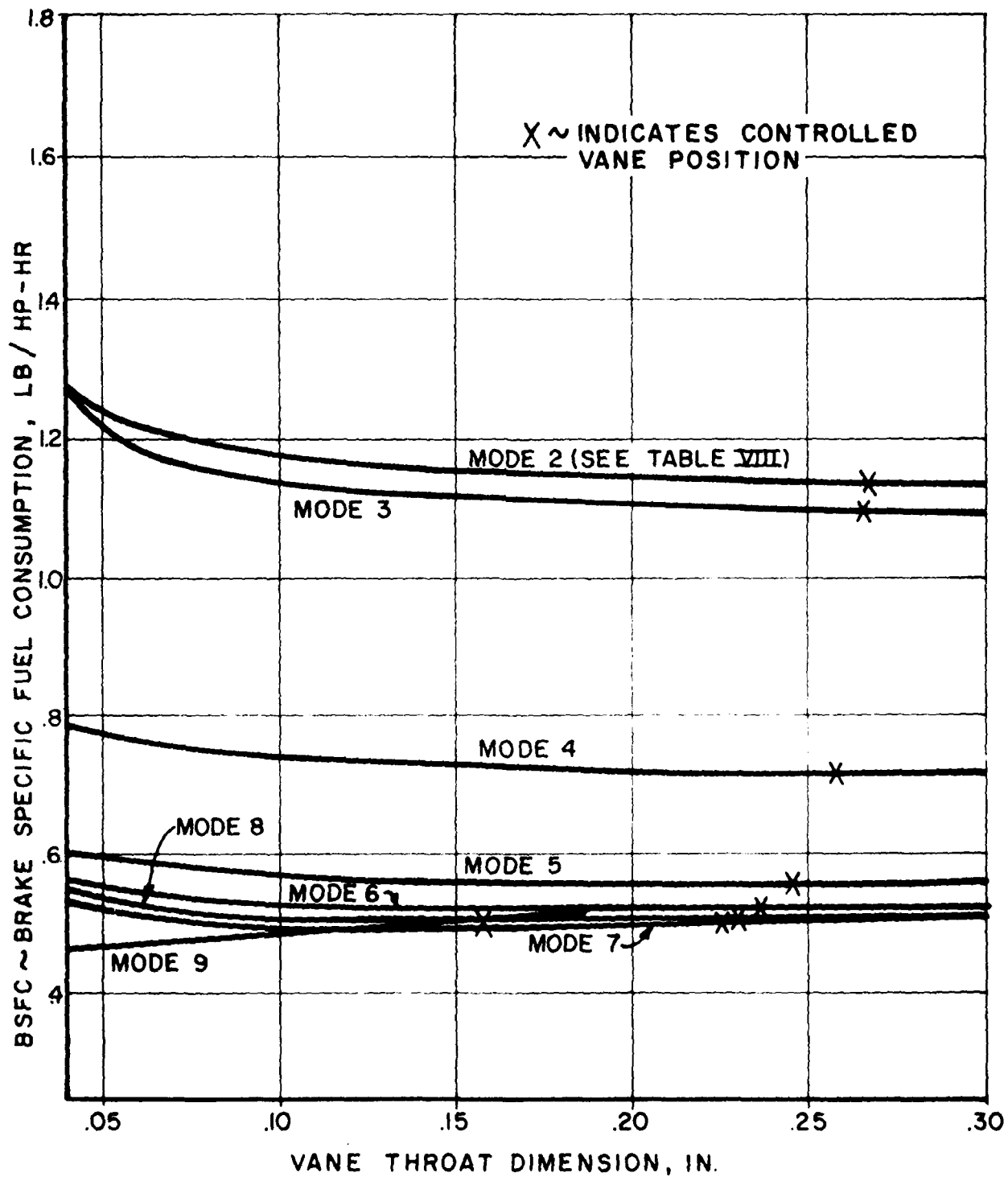


Table IX - Engine A LA4 fuel usage

Mode	VG	BSFC	HP	RPM	%FUEL
1	0.000	0.000	1.000	0.000	0.078
2	0.249	1.367	1.475	1789.950	0.047
3	0.248	1.303	2.148	2237.410	0.224
4	0.237	0.815	3.023	1785.300	0.072
5	0.223	0.612	4.141	1566.170	0.037
6	0.213	0.553	7.269	2013.720	0.015
7	0.202	0.510	11.856	2461.180	0.129
8	0.206	0.525	12.108	2601.870	0.206
9	0.134	0.430	28.720	2237.410	0.192

MPG= 48.593 Total Fuel= .148169 GAL N/V=35

Table X - Engine B LA4 fuel usage

Mode	VG	BSFC	HP	RPM	%FUEL
1	0.000	0.000	1.000	0.000	0.097
2	0.236	2.386	1.475	1789.958	0.054
3	0.235	2.283	2.148	2237.410	0.259
4	0.228	1.308	3.023	1785.300	0.076
5	0.218	0.908	4.141	1566.170	0.036
6	0.210	0.799	7.269	2013.720	0.015
7	0.202	0.717	11.856	2461.100	0.119
8	0.205	0.745	12.108	2601.870	0.193
9	0.158	0.514	20.720	2237.410	0.152

MPG= 32.0349 Total Fuel= .224755 GAL N/V=35

Table XI - Engine C LA4 fuel usage

Mode	VG	BSFC	HP	RPM	%FUEL
1	0.000	0.000	1.000	0.000	0.064
2	0.268	1.098	1.475	1789.950	0.041
3	0.267	1.054	2.148	2237.410	0.196
4	0.258	0.698	3.023	1785.300	0.066
5	0.246	0.545	4.141	1566.170	0.036
6	0.237	0.512	7.269	2013.720	0.016
7	0.226	0.488	11.856	2461.180	0.134
8	0.230	0.493	12.108	2601.870	0.209
9	0.150	0.494	20.720	2237.410	0.239

MPG= 52.589 Total Fuel= .136911 GAL N/V=35

Table XII - Comparison of control strategies with current 30KW gen set -
Mil. std. 705 duty cycle.

	<u>Strategy</u>			<u>Current</u>
	A	B	C	298
No-load fuel usage, gal	3.0	2.88	2.84	3.58
25% load fuel usage, gal	32.40	32.40	32.20	37.09
50% load fuel usage, gal	44.19	44.19	44.19	49.44
75% load fuel usage, gal	55.67	55.67	55.67	61.32
100% load fuel usage, gal	69.36	69.36	69.36	75.93
total fuel gal	204.62	204.50	204.26	227.40
Instantaneous no-load A/F	28.1	25.9	24.8	
No-load engine pressure difference, psig.	-1.42	-.84	-.69	

VI RECOMENDATION

The Aerodyne turbocharger has been developed to the point where the device is ready to be tested in an actual application environment. Also, the analytical study described herein indicated that the turbocharger can satisfy military 30KW DED generator set response requirements and reduce fuel consumption by 8 to 10%. Therefore, it is recommended that the six cylinder diesel engine currently used to drive the 30KW gen set be replaced by a reduced size diesel engine turbocharged with the Aerodyne turbocharger. The purpose of this unit would be to demonstrate fuel savings and compliance with Army generator set performance standards. This unit could also be used for initial durability testing.

APPENDIX

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.52

Rdq#/Hr:Mn	1/11:37	2/12:33	3/12:36	4/13:04	5/13:19
Engine Speed (RPM)	1461	1493	1511	1008	1004
Torque (ft-#)	2.4	250.7	252.1	47.9	96.5
Horsepower (HP)	0.7	71.3	72.5	9.2	18.4
sfc (#/HP-hr)	0.899	0.008	0.008	0.519	0.415
Air/Fuel Ratio	735.17	1072.37	1104.07	54.83	34.09
Dry Air/Fuel Ratio	723.36	1053.39	1084.14	53.83	33.46
Rel Humidity (%)	47	47	47	47	47
Dry Bulb Temp (R)	555.0	558.0	558.6	558.8	559.6
Engine delta P (psi)	-1.77	0.72	2.23	0.34	-0.17
Air Rate (#/hr)	441.1	632.7	651.4	261.7	261.0
Fuel Rate (#/hr)	0.600	0.590	0.590	4.773	7.656
Fuel time (sec)	60.0	61.0	61.0	754.2	470.2
Fuel Temp (R)	549.5	566.3	564.5	569.3	573.1
Crank Case Oil Temp (R)	574.0	673.1	679.2	659.8	663.0
Compressor Pressure Ratio	1.153	1.886	2.066	1.012	1.042
Corrected Flow (CFM)	101.6	147.2	152.0	60.3	60.3
Corrected Flow (#/sec)	0.129	0.188	0.194	0.077	0.077
Compressor Efficiency (%)	71.8	75.3	64.2	9.1	19.2
Compr Eff w/o .0008HT (%)	84.8	83.1	69.0	27.1	54.1
Inlet Temp (R)	554.6	559.1	559.6	560.5	561.5
Discharge Temp (R)	586.8	706.8	760.5	582.4	596.1
Inlet Press (psia)	14.383	14.296	14.254	14.447	14.437
Discharge Press (psia)	16.590	26.964	29.448	14.627	15.043
Corrected Speed (RPM/√O)	45134	90876	97893	22202	28757
Actual Speed (RPM)	46670	94350	101680	23080	29920
Turbine Expansion Ratio	1.279	1.861	1.932	1.037	1.052
Corrected Speed (rpm)	38332	56697	59337	17520	20716
% Des Corr Speed (%)	0.00	0.00	0.00	0.00	0.00
Vane Throat Dim. (in)	-0.250	-0.250	-0.250	0.290	0.290
Corrected Flow (#/sec)	0.120	0.164	0.168	0.096	0.104
Turbine Efficiency (%-meas T)	98.7	99.5	90.4	309.9	288.4
Turbine Efficiency (%-cmpr+brq Pwr, 80.8)	80.8	71.4	84.8	100.2	271.7
U/V'	0.670	0.637	0.648	0.785	0.784
Load Coef	1.099	1.227	1.075	2.516	2.347
Inlet Temp (R)	768.9	1436.4	1523.1	900.1	1082.0
Discharge Temp (R)	717.8	1219.3	1304.4	872.0	1038.9
Inlet Press (psia)	18.357	26.243	27.218	14.966	15.210
Discharge Press (psia)	14.354	14.101	14.087	14.433	14.456
Compressor Power (HP)	1.13	8.02	11.53	0.18	0.30
Eff-comprEff-turb	0.441	0.472	0.489	0.211	0.414
Eff-turb from Eff-compr w/o HT	51.97	56.76	70.79	77.76	76.60
Cp/Cv, ratio of spec heats	1.340	1.340	1.340	1.340	1.340
Cp (Btu/Lbm/R)	0.270	0.270	0.270	0.270	0.270

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.48

	6/13:44	7/13:54	8/14:16	9/14:43	10/14:52
Rdq#/Hr:Mn					
Engine Speed (RPM)	1497	1508	1013	1499	1997
Torque (ft-#)	54.1	108.2	1.6	1.9	1.9
Horsepower (HP)	15.4	31.1	0.3	0.5	0.7
sfc (#/HP-hr)	0.503	0.412	7.152	6.899	8.143
Air/Fuel Ratio	51.15	32.24	120.53	107.19	88.66
Dry Air/Fuel Ratio	50.18	31.62	118.26	105.08	86.91
Rel Humidity (%)	47	47	47	47	47
Dry Bulb Temp (R)	560.1	560.8	559.8	561.3	561.3
Engine delta P (psi)	-0.36	0.15	-0.45	-0.55	-0.89
Air Rate (#/hr)	397.1	412.5	266.0	401.0	521.6
Fuel Rate (#/hr)	7.763	12.794	2.207	3.741	5.883
Fuel time (sec)	463.7	281.4	814.9	480.7	305.7
Fuel Temp (R)	572.5	573.6	578.4	575.3	574.9
Crank Case Oil Temp (R)	669.8	676.9	657.3	663.8	669.3
Compressor Pressure Ratio	1.050	1.111	0.997	1.029	1.051
Corrected Flow (CFM)	92.1	95.7	61.5	93.1	121.6
Corrected Flow (#/sec)	0.117	0.122	0.078	0.119	0.155
Compressor Efficiency (%)	29.6	39.4	-3.3	26.5	32.5
Compr Eff w/o .0008HT(%)	51.7	64.0	-7.4	38.9	43.0
Inlet Temp (R)	562.2	562.9	562.6	562.6	562.4
Discharge Temp (R)	589.0	606.4	575.7	579.8	587.2
Inlet Press (psia)	14.374	14.387	14.418	14.376	14.311
Discharge Press (psia)	15.096	15.979	14.379	14.787	15.042
Corrected Speed (RPM/√O)	31207	39741	17581	27336	36263
Actual Speed (RPM)	32490	41400	18310	28470	37760
Turbine Expansion Ratio	1.074	1.101	1.028	1.067	1.110
Corrected Speed (rpm)	23779	27428	15379	23470	29490
% Des Corr Speed (%)	0.00	0.00	0.00	0.00	0.00
Vane Throat Dim. (in)	0.290	0.290	0.290	0.290	0.290
Corrected Flow (#/sec)	0.146	0.166	0.088	0.131	0.173
Turbine Efficiency (%-meas T)	165.8	98.8	111.2	-5.1	69.0
Turbine Efficiency (%-cmpr+brq Pwr)	168.5	157.4	111.5	161.6	123.1
U/V'	0.762	0.755	0.795	0.790	0.783
Load Coef	1.426	0.867	0.879	-0.041	0.562
Inlet Temp (R)	968.3	1181.7	735.2	763.2	850.4
Discharge Temp (R)	937.0	1151.6	728.9	763.9	833.5
Inlet Press (psia)	15.456	15.834	14.826	15.342	15.927
Discharge Press (psia)	14.395	14.376	14.477	14.381	14.350
Compressor Power (HP)	0.58	1.04	0.15	0.44	0.92
Eff-comprXEff-turb	0.400	0.517	-0.076	0.323	0.320
Eff-turb from Eff-compr w/o HT	77.34	80.82	102.79	83.08	74.24
Cp/Cv, ratio of spec heats	1.340	1.340	1.340	1.340	1.340
Cp (Btu/Lbm/R)	0.270	0.270	0.270	0.270	0.270

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.46

Rdg#/Hr:Mn	11/15:07	12/15:18	13/15:29	14/15:41	15/15:49
Engine Speed (RPM)	2007	2004	2498	2499	2505
Torque (ft-#)	53.2	104.4	2.4	48.8	143.7
Horsepower (HP)	20.3	39.8	1.1	23.2	68.5
sfc (#/HP-hr)	0.544	0.427	8.074	0.640	0.425
Air/Fuel Ratio	49.11	33.62	70.11	46.28	28.17
Drv Air/Fuel Ratio	48.14	32.91	68.62	45.29	27.58
Rel Humidity (%)	47	47	47	47	47
Drv Bulb Temp (R)	561.3	563.4	563.4	563.7	563.2
Engine delta P (psi)	-0.44	0.33	-0.97	-0.34	1.79
Air Pate (#/hr)	543.3	577.7	646.1	687.9	820.6
Fuel Rate (#/hr)	11.063	17.004	9.216	14.865	29.131
Fuel time (sec)	325.4	211.7	195.1	242.2	123.6
Fuel Temp (R)	575.8	573.2	577.9	577.1	574.4
Crank Case Oil Temp (R)	679.1	684.4	686.7	691.3	701.6
Compressor Pressure Ratio	1.113	1.216	1.124	1.220	1.556
Corrected Flow (CFM)	126.9	133.8	151.7	161.7	193.9
Corrected Flow (#/sec)	0.162	0.171	0.193	0.206	0.247
Compressor Efficiency (%)	44.0	52.4	45.2	54.2	62.4
Compr Eff w/o .0008HT(%)	58.3	66.9	54.1	63.7	69.0
Inlet Temp (R)	562.9	564.2	564.8	565.2	565.3
Discharge Temp (R)	602.6	625.7	607.3	626.2	687.3
Inlet Press (psia)	14.287	14.274	14.237	14.221	14.155
Discharge Press (psia)	15.899	17.363	16.003	17.348	22.023
Corrected Speed (RPM/√O)	41849	53905	48529	57622	79921
Actual Speed (RPM)	45680	56220	50640	60150	83330
Turbine Expansion Ratio	1.142	1.195	1.190	1.244	1.444
Corrected Speed (rpm)	32195	36345	36729	40452	49270
% Des Corr Speed (%)	0.00	0.00	0.00	0.00	0.00
Vane Throat Dim. (in)	0.290	0.290	0.290	0.290	0.290
Corrected Flow (#/sec)	0.197	0.218	0.217	0.241	0.290
Turbine Efficiency (%-meas T)	77.0	71.5	68.3	56.4	-217.4
Turbine Efficiency (%-cmpr+brq Pwr)	120.0	112.7	103.4	98.8	87.8
U/V'	0.759	0.741	0.758	0.746	0.708
Load Coef	0.668	0.651	0.594	0.507	-2.169
Inlet Temp (R)	1044.2	1241.1	986.0	1146.8	1483.7
Discharge Temp (R)	1015.5	1199.7	954.4	1109.5	1772.8
Inlet Press (psia)	16.338	17.032	16.970	17.684	20.232
Discharge Press (psia)	14.312	14.257	14.263	14.211	14.011
Compressor Power (HP)	1.54	2.63	2.16	3.38	8.57
Eff-comprXEff-turb	0.442	0.513	0.396	0.465	0.496
Eff-turb from Eff-compr w/o HT	75.69	76.70	73.14	73.06	71.87
Cp/Cv, ratio of spec heats	1.340	1.340	1.340	1.340	1.340
Cp (Btu/Lbm/R)	0.270	0.270	0.270	0.270	0.270

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.42

Rdq#/Hr:Mn	16/15:58	17/16:07	18/16:14
Engine Speed (RPM)	2504	2504	2003
Torque (ft-#)	194.4	204.9	229.9
Horsepower (HP)	92.7	97.7	87.7
sfc (#/HP-hr)	0.400	0.400	0.385
Air/Fuel Ratio	24.17	23.33	20.12
Dry Air/Fuel Ratio	23.64	22.77	19.64
Rel Humidity (%)	47	47	47
Dry Bulb Temp (R)	564.5	567.4	567.4
Engine delta P (psi)	3.04	3.32	3.27
Air Rate (#/hr)	895.2	912.8	679.9
Fuel Rate (#/hr)	37.033	39.118	33.784
Fuel time (sec)	97.2	92.0	106.6
Fuel Temp (R)	574.8	569.8	581.3
Crank Case Oil Temp (R)	711.5	710.0	712.4
Compressor Pressure Ratio	1.762	1.809	1.590
Corrected Flow (CFM)	212.6	217.2	160.6
Corrected Flow (#/sec)	0.271	0.277	0.205
Compressor Efficiency (%)	63.2	64.3	59.5
Compr Eff w/o .0008HT(%)	68.4	69.4	68.5
Inlet Temp (R)	566.9	568.3	570.7
Discharge Temp (R)	724.7	731.6	706.7
Inlet Press (psia)	14.102	14.088	14.221
Discharge Press (psia)	24.845	25.480	22.617
Corrected Speed (RPM/√O)	89618	91829	78298
Actual Speed (RPM)	93690	96120	82130
Turbine Expansion Ratio	1.571	1.600	1.376
Corrected Speed (rpm)	52806	53733	45146
% Des Corr Speed (%)	0.00	0.00	0.00
Vane Throat Dim. (in)	0.290	0.290	0.290
Corrected Flow (#/sec)	0.310	0.314	0.274
Turbine Efficiency (%-meas T)	64.3	66.8	68.2
Turbine Efficiency (%-cmpr+brq Pwr)	83.2	81.4	96.0
U/V'	0.687	0.687	0.693
Load Coef	0.680	0.708	0.709
Inlet Temp (R)	1632.8	1659.8	1716.6
Discharge Temp (R)	1517.6	1533.8	1625.3
Inlet Press (psia)	21.809	22.163	19.351
Discharge Press (psia)	13.880	13.849	14.059
Compressor Power (HP)	12.35	13.06	7.61
Eff-comprXEff-turb	0.482	0.480	0.514
Eff-turb from Eff-compr w/o HT	70.41	69.13	75.06
Cp/Cv, ratio of spec heats	1.340	1.340	1.340
Cp (Btu/Lbm/R)	0.270	0.270	0.269

"S/N69, 2.66I/D, Army#1 on Deere 4239T"

barometer is 29.48

Rd#/Hr:Mn	24/08:41	25/08:54	26/09:09	27/09:30	28/09:57
Engine Speed (RPM)	1510	1507	1507	1505	2000
Torque (ft-lb)	162.3	108.0	54.0	0.8	1.2
Horsepower (HP)	46.7	31.0	15.5	0.2	0.5
sfc (lb/HP-hr)	0.378	0.407	0.504	15.983	12.765
Air/Fuel Ratio	26.21	34.71	53.22	110.62	93.85
Dry Air/Fuel Ratio	25.82	34.18	52.39	108.85	92.29
Rel Humidity (%)	48	48	48	48	48
Dry Bulb Temp (R)	551.9	552.6	553.7	554.2	555.2
Engine delta P (psi)	1.18	0.34	-0.29	-0.56	-0.90
Air Rate (lb/hr)	462.5	437.3	415.3	405.3	547.4
Fuel Rate (lb/hr)	17.644	12.600	7.803	3.664	5.833
Fuel time (sec)	204.0	285.7	461.4	490.9	308.3
Fuel Temp (R)	564.3	568.4	575.2	573.6	568.1
Crank Case Oil Temp (R)	681.1	678.2	670.7	662.9	671.2
Compressor Pressure Ratio	1.275	1.173	1.090	1.056	1.103
Corrected Flow (CFM)	106.8	100.8	95.6	93.6	126.9
Corrected Flow (lb/sec)	0.136	0.129	0.122	0.119	0.162
Compressor Efficiency (%)	53.3	49.2	42.5	41.7	48.3
Comr Eff w/o .0008HT (%)	71.0	69.3	63.5	56.9	58.3
Inlet Temp (R)	554.1	554.7	555.1	555.3	555.8
Discharge Temp (R)	629.0	607.4	587.7	576.2	588.5
Inlet Press (psia)	14.338	14.365	14.390	14.350	14.305
Discharge Press (psia)	18.283	16.853	15.684	15.154	15.778
Corrected Speed (RPM/O)	55507	46570	37187	32193	42979
Actual Speed (RPM)	57370	48160	38470	33310	44490
Turbine Expansion Ratio	1.195	1.151	1.111	1.092	1.166
Corrected Speed (rpm)	35538	32124	28245	27439	34865
% Des Corr Speed (%)	0.00	0.00	0.00	0.00	0.00
Vane Throat Dim. (in)	0.235	0.235	0.235	0.235	0.235
Corrected Flow (lb/sec)	0.185	0.167	0.147	0.129	0.173
Turbine Efficiency (%-meas T)	93.9	106.8	132.4	32.6	66.1
Turbine Efficiency (%-cmpr+brq Pwr)	125.4	133.7	139.6	145.2	110.0
W/V	0.723	0.736	0.745	0.794	0.767
Load Coef	0.897	0.987	1.191	0.258	0.563
Inlet Temp (R)	1351.7	1165.8	962.2	764.4	844.6
Discharge Temp (R)	1293.0	1119.3	925.5	758.5	821.1
Inlet Press (psia)	17.107	16.511	15.970	15.718	16.678
Discharge Press (psia)	14.312	14.349	14.372	14.398	14.309
Compressor Power (HP)	2.45	1.54	0.95	0.59	1.40
Eff-comprXEff-turb	0.572	0.550	0.476	0.457	0.432
Eff-turb from Eff-compr w/o HT	80.53	79.29	74.89	80.30	74.00
cp/cv, ratio of spec heats	1.340	1.340	1.340	1.340	1.340
Cp (Btu/Lbm/R)	0.270	0.270	0.270	0.270	0.270

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.46

	19/06:59	20/07:34	21/07:50	22/08:05	23/08:29
Rdg#/Hr:Mn	1325	1000	1007	1002	1008
Engine Speed (RPM)	1325	1000	1007	1002	1008
Torque (ft-lb)	1.1	0.5	49.3	98.9	148.1
Horsepower (HP)	0.3	0.1	9.5	18.9	28.4
sfc (lb/HP-hr)	2.126	23.413	0.512	0.416	0.395
Air/Fuel Ratio	625.76	121.94	55.91	33.54	24.94
Dry Air/Fuel Ratio	618.20	120.38	55.16	33.10	24.58
Rel Humidity (%)	48	48	48	48	48
Dry Bulb Temp (R)	545.5	547.2	548.7	548.1	550.6
Engine delta P (psi)	-0.54	-0.46	-0.33	-0.17	0.24
Air Rate (lb/hr)	369.2	271.8	270.4	263.3	280.1
Fuel Rate (lb/hr)	0.590	2.229	4.836	7.950	11.232
Fuel time (sec)	61.0	806.6	371.9	229.1	320.5
Fuel Temp (R)	552.3	563.9	566.3	562.2	563.8
Crank Case Oil Temp (R)	613.6	650.5	656.2	661.6	670.3
Compressor Pressure Ratio	1.038	1.009	1.028	1.063	1.130
Corrected Flow (CFM)	84.4	62.2	62.0	60.3	64.6
Corrected Flow (lb/sec)	0.108	0.079	0.079	0.077	0.082
Compressor Efficiency (%)	33.8	10.9	19.3	25.7	32.7
Compr Eff w/o .0008HT(%)	49.7	22.2	49.2	60.7	60.9
Inlet Temp (R)	547.2	549.0	550.3	550.8	553.6
Discharge Temp (R)	564.6	562.5	573.2	588.4	614.0
Inlet Press (psia)	14.394	14.395	14.399	14.408	14.354
Discharge Press (psia)	14.943	14.530	14.807	15.312	16.227
Corrected Speed (RPM/√O)	28186	20869	25621	32499	42038
Actual Speed (RPM)	28950	21470	26390	33490	43430
Turbine Expansion Ratio	1.075	1.040	1.050	1.075	1.110
Corrected Speed (rpm)	24313	18238	20180	23377	27783
% Des Corr Speed (%)	0.00	0.00	0.00	0.00	0.00
Vane Throat Dim (in)	0.235	0.235	0.235	0.235	0.235
Corrected Flow (lb/sec)	0.116	0.088	0.097	0.102	0.116
Turbine Efficiency (%-meas T)	43.7	132.2	249.9	182.9	136.1
Turbine Efficiency (%-cmdr+brq Pwr)	157.2	238.9	243.7	214.2	192.1
U/V	0.776	0.788	0.782	0.743	0.736
Load Coef	0.363	1.063	2.045	1.657	1.255
Inlet Temp (R)	735.4	718.8	887.1	1064.5	1267.4
Discharge Temp (R)	728.9	708.3	857.1	1026.3	1219.9
Inlet Press (psia)	15.480	14.995	15.139	15.480	15.990
Discharge Press (psia)	14.403	14.420	14.420	14.401	14.408
Compressor Power (HP)	0.41	0.17	0.23	0.40	0.86
Eff-comprXEff-turb	0.392	0.182	0.355	0.432	0.512
Eff-turb from Eff-compr w/o HT	78.88	82.03	72.17	71.11	93.98
Cp/Cv, ratio of spec heats	1.340	1.340	1.340	1.340	1.340
Cp (Btu/Lbm/R)	0.270	0.270	0.270	0.270	0.270

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.48

	29/10:26	30/10:44	31/10:51	32/11:01	33/11:12
Rdq#/Hr:Mn					
Engine Speed (RPM)	2001	2001	2007	2006	2503
Torque (ft-#)	52.3	104.1	155.3	208.6	0.6
Horsepower (HP)	19.9	39.7	59.3	79.7	0.3
sfc (#/HP-hr)	0.562	0.432	0.387	0.377	31.446
Air/Fuel Ratio	51.51	36.47	29.41	24.25	77.36
Dry Air/Fuel Ratio	50.60	35.79	28.85	23.76	75.84
Rel Humidity (%)	48	48	48	48	48
Dry Bulb Temp (R)	557.1	559.1	559.8	561.1	560.4
Engine delta P (psi)	-0.27	0.69	1.71	3.14	-0.95
Air Rate (#/hr)	576.4	625.0	675.6	727.7	695.6
Fuel Rate (#/hr)	11.190	17.136	22.972	30.008	8.992
Fuel time (sec)	321.7	210.1	156.7	120.0	200.0
Fuel Temp (R)	571.4	573.5	571.6	570.9	576.4
Crank Case Oil Temp (R)	678.9	685.7	691.3	699.7	690.3
Compressor Pressure Ratio	1.194	1.340	1.492	1.699	1.220
Corrected Flow (CFM)	134.0	145.9	158.0	170.9	163.0
Corrected Flow (#/sec)	0.171	0.186	0.201	0.218	0.208
Compressor Efficiency (%)	55.7	60.7	63.0	63.2	56.9
Compr Eff w/o .0008HT (%)	67.0	70.4	71.1	69.7	63.7
Inlet Temp (R)	557.9	560.0	561.0	562.8	562.4
Discharge Temp (R)	610.0	640.5	668.9	708.6	620.1
Inlet Press (psia)	14.294	14.268	14.242	14.206	14.230
Discharge Press (psia)	17.067	19.119	21.245	24.140	17.354
Corrected Speed (RPM/√O)	52212	63615	73049	83761	57448
Actual Speed (RPM)	54150	66100	75970	87250	59820
Turbine Expansion Ratio	1.214	1.296	1.380	1.492	1.288
Corrected Speed (rpm)	38378	43160	46891	50781	43609
% Des Corr Speed (%)	0.00	0.00	0.00	0.00	0.00
Vane Throat Dim. (in)	0.235	0.235	0.235	0.235	0.235
Corrected Flow (#/sec)	0.195	0.218	0.236	0.253	0.216
Turbine Efficiency (%-meas T)	81.8	78.2	80.5	81.5	65.6
Turbine Efficiency (%-cmpr+brq Pwr)	108.3	103.1	97.7	93.3	96.9
U/V'	0.751	0.733	0.717	0.700	0.751
Load Coef	0.725	0.727	0.783	0.931	0.582
Inlet Temp (R)	1032.6	1216.6	1361.5	1531.2	976.0
Discharge Temp (R)	988.7	1152.4	1271.6	1407.5	932.7
Inlet Press (psia)	17.337	18.425	19.537	20.999	18.398
Discharge Press (psia)	14.282	14.221	14.159	14.073	14.219
Compressor Power (HP)	2.36	4.10	6.11	9.11	3.39
Eff-comprXEff-turb	0.511	0.547	0.548	0.533	0.476
Eff-turb from Eff-compr w/o HT	76.25	77.73	77.07	76.50	74.66
Cp/Cv, ratio of spec heats	1.340	1.340	1.340	1.340	1.340
Cp (Btu/Lbm/R)	0.270	0.270	0.270	0.270	0.270

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.46

	34/11:24	35/11:34	36/11:45	37/11:52	38/12:03
Rdg#/Hr:Mn					
Engine Speed (RPM)	2502	2503	2504	2503	2000
Torque (ft-lb)	49.0	97.9	144.7	195.0	239.6
Horsepower (HP)	23.3	46.7	69.0	92.9	91.2
sfc (lb/HP-hr)	0.655	0.479	0.426	0.400	0.375
Air/Fuel Ratio	49.58	38.68	31.92	27.43	22.29
Dry Air/Fuel Ratio	48.87	38.11	31.42	26.99	21.93
Rel Humidity (%)	36	36	36	36	36
Dry Bulb Temp (R)	559.9	560.5	562.5	563.2	563.3
Engine delta P (psi)	-0.09	1.11	2.28	3.59	4.01
Air Rate (lb/hr)	757.6	863.9	938.7	1019.8	763.6
Fuel Rate (lb/hr)	15.279	22.334	29.405	37.175	34.256
Fuel time (sec)	235.6	161.2	122.4	96.8	105.1
Fuel Temp (R)	577.2	576.5	570.4	568.3	570.2
Crank Case Oil Temp (R)	690.7	695.8	702.8	707.8	699.3
Compressor Pressure Ratio	1.369	1.608	1.836	2.098	1.509
Corrected Flow (CFM)	177.9	203.6	222.3	242.6	148.5
Corrected Flow (lb/sec)	0.227	0.259	0.283	0.309	0.189
Compressor Efficiency (%)	62.5	65.3	65.8	65.5	42.6
Comor Eff w/o .0008HT (%)	68.9	70.1	69.6	68.5	46.5
Inlet Temp (R)	561.6	562.2	563.6	564.8	564.8
Discharge Temp (R)	645.9	687.4	726.2	768.5	730.5
Inlet Press (psia)	14.195	14.150	14.099	14.048	17.190
Discharge Press (psia)	19.427	22.754	25.892	29.478	25.944
Corrected Speed (RPM/√O)	68839	82557	93151	103517	89813
Actual Speed (RPM)	71630	85950	97100	108020	93720
Turbine Expansion Ratio	1.381	1.546	1.699	1.881	1.566
Corrected Speed (rpm)	48433	54341	58609	62507	53047
% Des Corr Speed (%)	0.00	0.00	0.00	0.00	0.00
Vane Throat Dim. (in)	0.235	0.235	0.235	0.235	0.235
Corrected Flow (lb/sec)	0.239	0.264	0.277	0.288	0.262
Turbine Efficiency (%-meas T)	71.4	71.1	73.7	74.2	84.7
Turbine Efficiency (%-cmpr+brq Pwr)	93.1	88.3	85.4	82.3	89.3
U/V'	0.740	0.720	0.708	0.696	0.693
Load Coef	0.651	0.685	0.735	0.765	0.881
Inlet Temp (R)	1134.5	1297.6	1423.7	1549.0	1619.0
Discharge Temp (R)	1066.3	1196.1	1286.5	1374.3	1469.0
Inlet Press (psia)	19.520	21.647	23.614	25.884	21.931
Discharge Press (psia)	14.131	14.005	14.902	13.760	14.006
Compressor Power (HP)	5.48	9.54	13.66	18.80	10.97
Eff-comprXEff-turb	0.515	0.523	0.516	0.499	0.345
Eff-turb from Eff-compr w/o HT	74.77	74.59	74.07	72.82	74.30
Cp/Cv, ratio of spec heats	1.340	1.340	1.340	1.340	1.340
Cp (Btu/Lbm/R)	0.270	0.270	0.270	0.270	0.270

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.44

	39/12:11	40/12:40	41/12:53	42/13:07	43/13:19
Rdq#/Hr:Mn					
Engine Speed (RPM)	2503	1013	1006	1002	1508
Torque (ft-#)	207.3	98.8	148.4	196.7	107.8
Horsepower (HP)	98.8	19.1	28.4	37.5	31.0
sfc (#/HP-hr)	0.397	0.416	0.401	0.416	0.409
Air/Fuel Ratio	26.62	36.45	25.29	19.32	36.45
Dry Air/Fuel Ratio	26.23	35.95	24.93	19.06	35.93
Rel Humidity (%)	32	32	32	32	32
Dry Bulb Temp (R)	563.6	562.0	562.8	562.3	563.3
Engine delta P (psi)	3.90	-0.23	0.20	1.15	0.24
Air Rate (#/hr)	1043.5	289.1	288.3	301.5	461.3
Fuel Rate (#/hr)	39.207	7.931	11.401	15.603	12.657
Fuel time (sec)	91.8	226.8	315.8	230.7	284.4
Fuel Temp (R)	568.7	571.5	575.9	571.7	576.6
Crank Case Oil Temp (R)	708.5	669.5	673.5	681.7	678.5
Compressor Pressure Ratio	2.173	1.089	1.164	1.279	1.271
Corrected Flow (CFM)	248.7	67.1	67.1	70.2	107.8
Corrected Flow (#/sec)	0.317	0.085	0.086	0.090	0.137
Compressor Efficiency (%)	65.3	32.7	38.0	41.6	57.0
Compr Eff w/o .0008HT (%)	68.2	60.7	63.9	62.6	70.8
Inlet Temp (R)	565.2	565.2	566.0	566.8	566.4
Discharge Temp (R)	781.1	607.9	632.1	666.1	636.9
Inlet Press (psia)	14.036	14.414	14.373	14.371	14.330
Discharge Press (psia)	30.502	15.698	16.727	18.380	18.210
Corrected Speed (RPM/√O)	105943	36269	45711	56890	55178
Actual Speed (RPM)	110640	37860	47750	59470	57660
Turbine Expansion Ratio	1.938	1.107	1.151	1.202	1.258
Corrected Speed (rpm)	63310	26205	30412	34913	38444
% Des Corr Speed (%)	0.00	0.00	0.00	0.00	0.00
Vane Throat Dim. (in)	0.235	0.177	0.177	0.177	0.177
Corrected Flow (#/sec)	0.290	0.110	0.116	0.128	0.161
Turbine Efficiency (%-meas T)	73.7	152.4	125.1	115.5	100.9
Turbine Efficiency (%-comp+brq Pwr)	81.3	168.8	156.1	147.6	109.4
U/V	0.690	0.703	0.696	0.700	0.693
Load Coef	0.773	1.544	1.290	1.178	1.051
Inlet Temp (R)	1584.1	1082.7	1278.7	1505.0	1166.8
Discharge Temp (R)	1399.6	1037.3	1219.7	1423.5	1095.7
Inlet Press (psia)	26.598	15.929	16.528	17.233	17.975
Discharge Press (psia)	13.722	14.385	14.364	14.336	14.290
Compressor Power (HP)	20.40	0.63	1.07	1.88	2.47
Eff-compXEff-turb	0.493	0.437	0.480	0.510	0.527
Eff-turb from Eff-comp w/o HT	72.24	72.11	75.12	81.41	74.48
Cp/Cv, ratio of spec heats	1.340	1.340	1.340	1.340	1.340
Cp (Btu/lbm/R)	0.270	0.270	0.270	0.269	0.270

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.42

Rdg#/Hr:Mn	44/13:35	45/13:47
Engine Speed (RPM)	1501	1512
Torque (ft-#)	162.0	216.3
Horsepower (HP)	46.3	62.3
sfc (#/HP-hr)	0.383	0.379
Air/Fuel Ratio	27.81	23.13
Dry Air/Fuel Ratio	27.48	22.86
Rel Humidity (%)	26	26
Dry Bulb Temp (R)	563.8	563.5
Engine delta P (psi)	1.25	2.73
Air Rate (#/hr)	493.7	545.9
Fuel Rate (#/hr)	17.755	23.600
Fuel time (sec)	202.8	152.5
Fuel Temp (R)	572.1	570.2
Crank Case Oil Temp (R)	682.8	689.6
Compressor Pressure Ratio	1.410	1.622
Corrected Flow (CFM)	115.7	128.0
Corrected Flow (#/sec)	0.147	0.163
Compressor Efficiency (%)	59.3	59.5
Compr Eff w/o .0008HT(%)	70.9	68.2
Inlet Temp (R)	566.4	566.7
Discharge Temp (R)	665.1	708.1
Inlet Press (psia)	14.286	14.280
Discharge Press (psia)	20.145	23.164
Corrected Speed (RPM/√O)	65350	78115
Actual Speed (RPM)	68290	81650
Turbine Expansion Ratio	1.327	1.440
Corrected Speed (rpm)	42611	47438
% Des Corr Speed (%)	0.00	0.00
Vane Throat Dim. (in)	0.177	0.177
Corrected Flow (#/sec)	0.177	0.196
Turbine Efficiency (%-meas T)	93.4	92.9
Turbine Efficiency (%-cmpr+brq Pwr)	106.2	100.5
U/V'	0.693	0.684
Load Coef	0.972	0.993
Inlet Temp (R)	1332.2	1536.6
Discharge Temp (R)	1241.7	1407.3
Inlet Press (psia)	18.896	20.430
Discharge Press (psia)	14.234	14.187
Compressor Power (HP)	3.85	6.37
Eff-comprXEff-turb	0.544	0.528
Eff-turb from Eff-compr w/o HT	76.74	77.46
Cp/Cv, ratio of spec heats	1.340	1.340
Cp (Btu/Lbm/R)	0.270	0.270

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.46

Rdq#/Hr:Mn	46/08:04	47/09:10	48/09:18	49/09:27	50/09:37
Engine Speed (RPM)	1478	1998	2006	2507	1512
Torque (ft-#)	21.5	156.5	208.7	97.1	247.1
Horsepower (HP)	6.1	59.5	79.7	46.3	71.1
sfc (#/HP-hr)	-0.098	0.397	0.380	0.500	0.381
Air/Fuel Ratio	-676.44	32.87	28.12	43.93	21.19
Dry Air/Fuel Ratio	-667.35	32.36	27.65	43.19	20.83
Rel Humidity (%)	51	50	50	50	50
Dry Bulb Temp (R)	546.9	552.0	554.2	554.6	554.6
Engine delta P (psi)	-0.75	1.79	3.21	0.35	3.71
Air Rate (#/hr)	399.1	777.2	850.9	1019.1	574.6
Fuel Rate (#/hr)	-0.590	23.647	30.255	23.197	27.115
Fuel time (sec)	61.0	152.2	119.0	155.2	132.8
Fuel Temp (R)	549.3	559.3	563.9	567.6	564.8
Crank Case Oil Temp (R)	610.5	694.0	701.3	703.1	696.9
Compressor Pressure Ratio	1.108	1.800	2.086	2.057	1.770
Corrected Flow (CFM)	91.5	181.2	199.4	240.6	133.8
Corrected Flow (#/sec)	0.117	0.231	0.254	0.307	0.171
Compressor Efficiency (%)	52.3	65.4	64.7	66.3	61.3
Compr Eff w/o .0008HT (%)	69.4	69.6	68.0	68.5	69.3
Inlet Temp (R)	547.6	553.2	555.1	555.8	556.9
Discharge Temp (R)	578.9	708.1	755.9	747.8	718.1
Inlet Press (psia)	14.357	14.191	14.143	14.043	14.253
Discharge Press (psia)	15.914	25.549	29.502	28.883	25.230
Corrected Speed (RPM/O)	39543	90353	100154	102004	84937
Actual Speed (RPM)	40630	93310	103610	105590	98010
Turbine Expansion Ratio	1.161	1.694	1.888	2.071	1.519
Corrected Speed (rpm)	32005	58724	61975	67459	49976
% Des Corr Speed (%)	0.00	0.00	0.00	0.00	0.00
Vane Throat Dim. (in)	0.177	0.177	0.177	0.177	0.177
Corrected Flow (#/sec)	0.124	0.219	0.229	0.233	0.201
Turbine Efficiency (%-meas T)	99.5	80.1	80.1	74.1	92.6
Turbine Efficiency (%-cmpr+brq Pwr)	115.7	90.4	87.1	84.5	95.1
U/V'	0.713	0.712	0.688	0.705	0.675
Load Coef	0.980	0.790	0.845	0.745	1.017
Inlet Temp (R)	835.9	1309.6	1449.7	1270.8	1608.6
Discharge Temp (R)	801.7	1171.5	1270.1	1102.9	1455.9
Inlet Press (psia)	16.660	23.762	26.296	28.530	21.521
Discharge Press (psia)	14.349	14.031	13.925	13.776	14.167
Compressor Power (HP)	0.89	10.71	15.40	17.94	7.76
Eff-comprXEff-turb	0.469	0.534	0.517	0.517	0.519
Eff-turb from Eff-compr w/o HT	67.50	76.76	76.04	75.42	74.93
Cp/Cv, ratio of spec heats	1.340	1.340	1.340	1.340	1.340
Cp (Btu/Lbm/R)	0.270	0.270	0.270	0.270	0.270

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.46

Rdg#/Hr:Mn	51/09:56	52/10:12	53/10:21	54/10:33	55/10:45
Engine Speed (RPM)	1503	1008	2003	2498	1010
Torque (ft-#)	54.4	49.3	244.1	1.0	197.1
Horsepower (HP)	15.6	9.5	93.1	0.5	37.9
sfc (#/HP-hr)	0.518	0.523	0.375	23.062	0.407
Air/Fuel Ratio	53.79	55.24	25.90	83.43	21.23
Dry Air/Fuel Ratio	52.86	54.29	25.43	81.92	20.95
Rel Humidity (%)	50	50	50	50	50
Dry Bulb Temp (R)	555.3	555.1	556.4	556.6	556.6
Engine delta P (psi)	-0.46	-0.42	4.26	-4.83	0.28
Air Rate (#/hr)	434.2	273.6	903.5	915.1	327.6
Fuel Rate (#/hr)	8.072	4.953	34.890	10.969	15.432
Fuel time (sec)	446.0	363.1	103.2	164.0	233.3
Fuel Temp (R)	574.4	573.8	564.9	570.1	575.7
Crank Case Oil Temp (R)	674.7	664.8	685.6	688.2	684.9
Compressor Pressure Ratio	1.156	1.049	2.279	1.771	1.322
Corrected Flow (CFM)	100.5	63.1	212.4	215.4	75.4
Corrected Flow (#/sec)	0.128	0.080	0.271	0.275	0.096
Compressor Efficiency (%)	53.7	27.2	65.3	68.4	43.7
Compr Eff w/o .0008HT (%)	69.8	54.5	68.2	70.5	60.0
Inlet Temp (R)	557.0	557.3	556.9	557.5	559.3
Discharge Temp (R)	600.9	585.6	783.6	702.2	665.7
Inlet Press (psia)	14.347	14.404	14.119	14.108	14.451
Discharge Press (psia)	16.584	15.112	32.180	24.983	19.103
Corrected Speed (RPM/√O)	44650	29724	106671	95646	62210
Actual Speed (RPM)	46270	30810	110530	99160	64600
Turbine Expansion Ratio	1.189	1.078	2.014	2.147	1.316
Corrected Speed (rpm)	33870	23275	64425	70255	38528
% Des Corr Speed (%)	0.00	0.00	0.00	0.00	0.00
Vane Throat Dim. (in)	0.177	0.177	0.177	0.111	0.111
Corrected Flow (#/sec)	0.145	0.097	0.235	0.179	0.125
Turbine Efficiency (%-meas T)	105.2	190.1	81.3	75.8	101.8
Turbine Efficiency (%-comp+brq Pwr)	113.4	189.0	84.8	77.9	110.5
U/V'	0.702	0.725	0.685	0.720	0.630
Load Coef	1.068	1.810	0.867	0.731	1.250
Inlet Temp (R)	968.0	908.9	1526.7	1033.3	1458.0
Discharge Temp (R)	920.4	872.9	1318.5	884.0	1354.0
Inlet Press (psia)	17.039	15.527	27.919	29.815	18.820
Discharge Press (psia)	14.336	14.398	13.863	13.885	14.290
Compressor Power (HP)	1.38	0.36	18.57	12.15	2.40
Eff-compRXEff-turb	0.496	0.390	0.510	0.477	0.400
Eff-turb from Eff-comp w/o HT	71.02	71.59	74.91	67.71	67.00
Cp/Cv, ratio of spec heats	1.340	1.340	1.340	1.340	1.340
Cp (Btu/Lbm/R)	0.270	0.270	0.270	0.270	0.270

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.46

Rdg#/Hr:Mn	56/10:56	57/11:08	58/12:38	59/13:51	60/14:00
Engine Speed (RPM)	1508	1495	875	852	990
Torque (ft-#)	216.0	250.6	0.5	0.8	0.4
Horsepower (HP)	62.0	71.3	0.1	0.1	0.3
sfc (#/HP-hr)	0.377	0.377	25.702	15.557	21.883
Air/Fuel Ratio	26.83	24.45	112.56	114.96	121.53
Dry Air/Fuel Ratio	26.31	24.00	111.07	113.46	119.91
Rel Humidity (%)	50	50	35	32	32
Dry Bulb Temp (R)	558.3	557.7	558.3	560.4	561.1
Engine delta P (psi)	1.57	2.60	-2.12	-1.89	-2.94
Air Rate (#/hr)	626.4	658.3	241.0	232.1	302.6
Fuel Rate (#/hr)	23.351	26.920	2.141	2.019	2.490
Fuel time (sec)	154.2	133.7	839.9	890.8	722.2
Fuel Temp (R)	566.5	571.7	577.7	575.6	577.0
Crank Case Oil Temp (R)	687.5	690.5	653.1	650.0	652.6
Compressor Pressure Ratio	1.943	2.112	1.110	1.104	1.151
Corrected Flow (CFM)	145.9	153.4	55.7	53.8	70.2
Corrected Flow (#/sec)	0.186	0.195	0.071	0.069	0.089
Compressor Efficiency (%)	62.1	61.6	49.3	50.7	53.6
Comor Eff w/o .0008HT (%)	66.8	65.8	64.1	68.1	63.0
Inlet Temp (R)	559.8	559.8	560.8	562.3	562.3
Discharge Temp (R)	748.4	776.5	595.2	594.1	605.4
Inlet Press (psia)	14.285	14.282	14.423	14.382	14.386
Discharge Press (psia)	27.758	30.166	16.006	15.877	16.561
Corrected Speed (RPM/√O)	94833	99656	38325	36669	44286
Actual Speed (RPM)	98520	103530	39850	38180	46110
Turbine Expansion Ratio	1.858	1.962	1.259	1.233	1.355
Corrected Speed (rpm)	59077	60070	33032	31728	37896
% Des Corr Speed (%)	0.00	0.00	0.00	0.00	0.00
Vane Throat Dim. (in)	0.111	0.111	0.043	0.043	0.043
Corrected Flow (#/sec)	0.169	0.175	0.066	0.065	0.078
Turbine Efficiency (%-meas T _i)	91.9	83.9	67.1	63.0	72.8
Turbine Efficiency (%-comp+brq Pwr)	86.3	84.7	101.1	104.7	89.3
U/V'	0.664	0.650	0.596	0.600	0.599
Load Coef	0.928	0.944	0.944	0.877	1.016
Inlet Temp (R)	1442.5	1540.7	754.9	751.1	767.9
Discharge Temp (R)	1264.0	1331.6	722.9	723.8	721.8
Inlet Press (psia)	26.188	27.569	18.125	17.768	19.498
Discharge Press (psia)	14.095	14.055	14.398	14.410	14.390
Compressor Power (HP)	10.40	12.65	0.60	0.52	1.05
Eff-comprXEff-turb	0.479	0.472	0.349	0.366	0.358
Eff-turb from Eff-compr w/o HT	71.72	71.66	54.43	53.70	56.74
Cp/Cv, ratio of spec heats	1.340	1.340	1.340	1.340	1.340
Cp (Btu/lbm/R)	0.270	0.270	0.270	0.270	0.270

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.44

Rdq#/Hr:Mn	61/14:18	62/14:26	63/14:39	64/14:48	65/15:01
Engine Speed (RPM)	1495	1995	1002	747	1508
Torque (ft-#)	1.0	1.1	213.9	178.4	162.1
Horsepower (HP)	0.3	0.4	40.8	25.4	46.5
sfc (#/HP-hr)	17.902	22.071	0.482	0.582	0.392
Air/Fuel Ratio	101.18	86.94	15.78	13.15	23.54
Drv Air/Fuel Ratio	99.88	85.78	15.57	12.97	23.22
Rel Humidity (%)	31	31	31	31	31
Dry Bulb Temp (R)	561.0	562.3	562.0	562.4	562.5
Engine delta P (psi)	-6.10	-11.56	-3.03	-1.22	0.80
Air Rate (#/hr)	515.6	801.8	310.7	194.2	429.1
Fuel Rate (#/hr)	5.096	9.222	19.688	14.771	18.227
Fuel time (sec)	352.9	195.0	182.9	121.8	197.5
Fuel Temp (R)	576.0	574.8	572.3	571.7	570.6
Crank Case Oil Temp (R)	664.8	675.4	677.0	678.4	675.9
Compressor Pressure Ratio	1.456	1.912	1.493	1.241	1.189
Corrected Flow (CFM)	120.2	188.8	72.8	45.3	100.1
Corrected Flow (#/sec)	0.153	0.241	0.093	0.058	0.128
Compressor Efficiency (%)	68.8	67.4	43.5	31.3	46.6
Comor Eff w/o .0008HT(%)	72.7	69.2	57.0	57.8	71.8
Inlet Temp (R)	562.5	562.7	572.4	569.7	565.2
Discharge Temp (R)	655.3	732.7	732.3	685.3	626.4
Inlet Press (psia)	14.310	14.167	14.368	14.382	14.327
Discharge Press (psia)	20.836	27.094	21.458	17.841	17.015
Corrected Speed (RPM/√O)	68515	95453	76437	54579	47841
Actual Speed (RPM)	71350	99420	80360	57200	49940
Turbine Expansion Ratio	1.889	2.766	1.715	1.327	1.131
Corrected Speed (rpm)	55051	70942	44196	33150	30422
% Des Corr Speed (%)	0.00	0.00	0.00	0.00	0.00
Vane Throat Dim. (in)	0.043	0.043	0.043	0.043	0.290
Corrected Flow (#/sec)	0.102	0.120	0.100	0.077	0.185
Turbine Efficiency (%-meas T)	70.7	72.6	89.7	116.1	101.2
Turbine Efficiency (%-cmpr+brq Pwr)	74.5	72.1	73.2	112.8	143.2
U/V	0.614	0.641	0.530	0.540	0.742
Load Coef	0.937	0.883	1.599	1.992	0.919
Inlet Temp (R)	871.3	1018.7	1714.8	1544.3	1397.7
Discharge Temp (R)	770.5	836.8	1516.4	1417.1	1352.4
Inlet Press (psia)	26.933	38.654	24.491	19.065	16.215
Discharge Press (psia)	14.256	13.977	14.282	14.372	14.333
Compressor Power (HP)	4.28	12.58	3.59	1.15	1.61
Eff-comprEff-turb	0.432	0.435	0.266	0.281	0.565
Eff-turb from Eff-compr w/o HT	59.50	62.84	46.67	48.60	78.65
Cp/Cv, ratio of spec heats	1.340	1.340	1.340	1.340	1.340
Cp (Btu/Lbm/R)	0.270	0.270	0.269	0.269	0.270

"S/N69, 2.66I/D, Army#1, on Deere 4239T"

barometer is 29.42

Rd: #/Hr: Mn	66/15:11	67/15:20
Engine Speed (RPM)	1998	2010
Torque (ft-#)	156.3	208.4
Horsepower (HP)	59.5	79.8
sfc (#/HP-hr)	0.392	0.385
Air/Fuel Ratio	25.81	21.28
Drv Air/Fuel Ratio	25.46	20.98
Rel Humidity (%)	31	30
Drv Bulb Temp (R)	562.9	564.2
Engine delta P (psia)	1.21	2.55
Air Rate (#/hr)	601.8	654.0
Fuel Rate (#/hr)	23.315	30.735
Fuel time (sec)	154.4	117.1
Fuel Temp (R)	575.6	574.2
Crank Case Oil Temp (R)	691.6	700.4
Compressor Pressure Ratio	1.326	1.497
Corrected Flow (CFM)	141.2	154.0
Corrected Flow (#/sec)	0.180	0.196
Compressor Efficiency (%)	56.1	59.3
Compr Eff w/o .0008HT (%)	68.6	69.4
Inlet Temp (R)	565.4	566.8
Discharge Temp (R)	650.1	683.8
Inlet Press (psia)	14.249	14.216
Discharge Press (psia)	18.898	21.287
Corrected Speed (RPM/O)	62468	73392
Actual Speed (RPM)	65220	76720
Turbine Expansion Ratio	1.247	1.329
Corrected Speed (rpm)	39379	43438
% Des Corr Speed (%)	0.00	0.00
Vane Throat Dim. (in)	0.290	0.290
Corrected Flow (#/sec)	0.239	0.263
Turbine Efficiency (%-meas T)	74.9	68.9
Turbine Efficiency (%-compr+brq Pwr)	106.8	98.8
U/V'	0.723	0.705
Load Coef	0.716	0.693
Inlet Temp (R)	1422.8	1618.0
Discharge Temp (R)	1362.7	1539.3
Inlet Press (psia)	17.686	18.739
Discharge Press (psia)	14.187	14.097
Compressor Power (HP)	3.94	6.18
Eff-comprXEff-turb	0.526	0.523
Eff-turb from Eff-compr w/o HT	76.76	75.38
gamma/Cv, ratio of spec heats	1.340	1.340
Cp (Btu/Lbm/R)	0.270	0.270

